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XVII

MARCH–APRIL 1896

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THE UNIVERSITY OF CHICAGO

THE SUMMER QUARTER

The University of Chicago announced the courses of study offered for the Third Summer Quarter early in March. By the constitution of the University the Summer Quarter is an integral part of the college year, and work done in the months of July, August, and September may be counted towards a degree by any candidate. Accordingly there will be no diminution in the opportunities offered for study and investigation. Every department will be in operation with a full corps of instructors; all libraries and laboratories will be open for the use of students.

While regular students are encouraged to make the Summer Quarter a part of their college course it is hoped and expected that many persons will enter the University for the Summer Quarter only, or for a single term of it. The programme of courses is therefore especially adapted to meet the needs of such persons. Many beginning courses are offered, and courses of study are so arranged that a student may devote his entire time for six weeks or three months to the mastery of a single subject under the direction of several instructors. In this way a student who desires to advance in any subject beyond the limits fixed by the resources of the preparatory school, either for the purpose of anticipating some portion of his college course or to fit himself for independent work in his chosen field of study or profession, can pursue his plan most profitably.

For teachers it is believed that the opportunity offered by the Summer Quarter will prove of exceptional value. A number of courses have been arranged and will be conducted with special reference to meeting and discussing practical educational problems. From inquiries already received it is certain that a large number of teachers in both college and secondary grades will be in attendance at the University. The advantages to individual teachers from mutual discussion and association need not be pointed out. Finally, the opportunity of coming into close contact with a university system representing the ideals and methods of higher education, the advantages of sharing even for a short time in the interests of university life must prove a source of increased enthusiasm and power to every teacher.

For graduate students the University offers substantially the same opportunities for advanced work in the Summer as during any other quarter of the year. In the last Summer Quarter three hundred and ninety-four graduate students were registered.

For undergraduates and teachers desirous of pursuing studies for the bachelor degree the prescribed courses will be repeated as well as the elective work offered in the Academic and University Colleges. Many of the courses will be arranged as Majors (courses requiring two hours of class room work per day for six weeks), thus enabling students who can spend but one term at the University to get complete credit for the work which they perform.

Admission to the University for the Summer Quarter is gained by examination. A detailed list of requirements is given in the *Circular of Information*. Teachers may be admitted to courses in departments in which they have given instruction, *without examination*, in accordance with a special regulation of the University Faculty.

The tuition fee for the quarter is forty dollars; for either term twenty dollars. Rooms in the college dormitories may be rented at prices varying from twenty-five to fifty dollars per quarter.

A Special *Circular of Information* for the Summer Quarter will be sent after March 1st, on application to

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PLATE XXIII.

QUIESCENT PROMINENCE PHOTOGRAPHED AT THE KENWOOD OBSERVATORY
1894, JULY 3, 4^h 10^m CHICAGO M. T.

THE
ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

VOLUME III MAY 1896 NUMBER 5

THE MODERN SPECTROSCOPE. XVIII.

ON THE CONDITIONS OF MAXIMUM EFFICIENCY IN THE USE OF THE SPECTROGRAPH.

By F. L. O. WADSWORTH.

IN the last paper of the Modern Spectroscope series I briefly indicated the conditions which it was necessary to fulfill in order that the *photographic* resolution of a given optical instrument should be equal to the *theoretical* visual resolution. In this case, which was the only one considered, we have to deal with the resolution of very fine lines or points whose angular width, as viewed from the camera, is negligible in comparison with the angle subtended by a wave-length of light at a distance equal to the diameter of the object-glass, such, for example, as stars, fine details on the lunar or the solar surface, and in the case of the spectrograph, the spectral images of *very* narrow slits. In this paper I propose to consider the whole question of photographic resolution more in detail and to point out that in spectrographic work, with slits of the width that are practically used, the conditions of efficiency are very different in the case of stars and other sources of very small angular magnitude, from the case of extended sources such as the Sun, the nebulæ, and the planets.

Although the conditions of efficiency in the case of the spectroscope have been discussed by a number of writers, and are now generally (though unfortunately not universally) recognized in spectroscopic work, no one has, as far as I have been able to find, considered this general question in the case of the spectrograph, save from the standpoint of practical experiment. Indeed, Mr. Newall, in discussing this question in his recent interesting paper on the new Bruce spectrograph of the Cambridge Observatory,[1] says: "The only considerations which bear on this point (relation of focal length of camera to resolving power of instrument) are practical." I do not agree with Mr. Newall in this statement, for, as I hope to show, there are certain theoretical considerations which are at least useful in indicating the limits, so to speak, of the design, not only as regards this particular point, which is perhaps one of those of the greatest importance, but as regards others of almost equal weight.

In considering the general conditions of efficiency in the case of the *astronomical spectroscope*,[2] the condition which I assumed as a basis of comparison was that of a constant visual resolving power r. In the case of the *spectrograph* we shall correspondingly assume a constant photographic resolution, a quantity which we will designate as q, and which will depend on the visual resolution r, on the angular aperture of the camera objective β, and on the structure or grain of the photographic plate. Let us first eliminate the question of the spectroscope train entirely, and consider only the resolution of the camera lens. The function of this is to form diffraction images of a series of points or lines, and it is evident that only those will be "resolved" (either visually or photographically) whose angular separation exceeds a certain limiting value depending on the width of the diffraction pattern, *i. e.*, both on the diameter of the objective and on the angular width of the lines or points themselves. Let us call this limiting value α in the case of visual

[1] *Ap. J.*, **3**, 276, April 1896.

[2] *Ap. J.*, **1**, 52–79, January 1895.

observations and a_q in the case of photographic records. Then, as we have already shown in the preceding paper, we have for the case of *narrow* lines or points

$$a_0 = m\frac{\lambda}{a'} \tag{1}$$

$$a_q = \frac{ne}{f'} = \frac{ne\beta}{a'} \tag{2}$$

where a' and f' and β are respectively the linear aperture, focal length and angular aperture of the lens, m is a constant varying from unity for a rectangular aperture to about 1.1 for a circular aperture (Rayleigh, Wave Theory, *Enc. Brit.*, **24**, 434), n, a whole number (taken as 4 in the preceding paper), and e the mean diameter of the silver grains.

Next let us consider the case of lines having a width s, and of uniform brightness across their whole width. Under these conditions it has been generally assumed that for distinct resolution the angular distance between the contiguous edges of the two lines must be equal to the resolving power of the aperture through which they are viewed. According to this assumption the angular distance between the centers of the two lines of width s, which would be just resolved, would have to be

$$\frac{1}{f'}\left(s\frac{f'}{f} + m\frac{\lambda}{a'}f'\right) = \left(\frac{s}{f} + m\frac{\lambda}{a'}\right) = \frac{1}{a'}\left(s\psi + m\lambda\right), \tag{3}$$

where ψ is the angular magnitude of the aperture a', as viewed from the line s, and f is the distance of the line itself from the lens. This is the assumption on which the ordinary formula for the purity of a spectrum is based. But I have recently found that it may be shown, both by theory and by experiment, that this assumption is incorrect, and that the resolving power of an instrument for wide lines is considerably greater than is indicated by the above expression. As this point has apparently escaped notice heretofore it may be considered a little in detail.

The diffraction pattern due to a line of width s, or angular width $\sigma = \frac{s}{f}$, is found by integrating the effect due to each linear element over the whole width of the line. In the case of

a rectangular aperture the diffraction pattern due to each linear element is represented by the dotted curves of Fig. 7 (*Ap. J.*, March 1896, p. 188), whose equation, as is well known, is

$$I = C\frac{\sin^2\frac{\pi}{a}\phi}{\left(\frac{\pi}{a}\phi\right)^2},$$

ϕ being the angular distance from the center of the diffraction image. The intensity at any point γ due to the effect of all of the elements of a line of uniform brightness, will therefore be

$$I' = C\int_{\frac{\sigma}{2}}^{\frac{\sigma}{2}} \frac{\sin^2\frac{\pi}{a}(\gamma-\phi)}{\left[\frac{\pi}{a}(\gamma-\phi)\right]^2} d\phi$$

$$= C'\int_{\frac{\pi}{a}\left(\gamma-\frac{\sigma}{2}\right)}^{\frac{\pi}{a}\left(\gamma+\frac{\sigma}{2}\right)} \frac{\sin^2 x}{x^2} dx = f(\gamma, \sigma) \qquad (4)$$

The value of the definite integral in (4) cannot be found directly in terms of γ and σ, but it can easily be evaluated by mechanical quadrature for different values of these variables. It was so evaluated for values of σ, varying from $\sigma=0$ to $\sigma=3a$. The diffraction patterns for three sources of width $\sigma=a$, $\sigma=2a$ and $\sigma=3a$ respectively are shown in dotted lines in Plate XXIV., Fig. 1.

In order that a double line may be resolved it is necessary that the intensity at the center of the diffraction pattern of the double source (shown in full lines in Fig. 1), should be about 0.8, the intensity at the maxima corresponding to the centers of the two geometrical images. In order that this may be the case the distance between these centers in the three cases illustrated in the figure must be

for $\sigma =$	a	angular	distance	between	centers	$= 1.27\,a = \sigma + .27\,a$
$\sigma =$	$2a$	"	"	"	"	$= 2.21\,a = \sigma + .21\,a$
$\sigma =$	$3a$	"	"	"	"	$= 3.20\,a = \sigma + .20\,a$
or in general,		"	"	"	"	$= \Sigma = \sigma + \delta$

From these and intermediate values the curve in Fig. 2, which represents the relation between the angular width of the

PLATE XXIV.

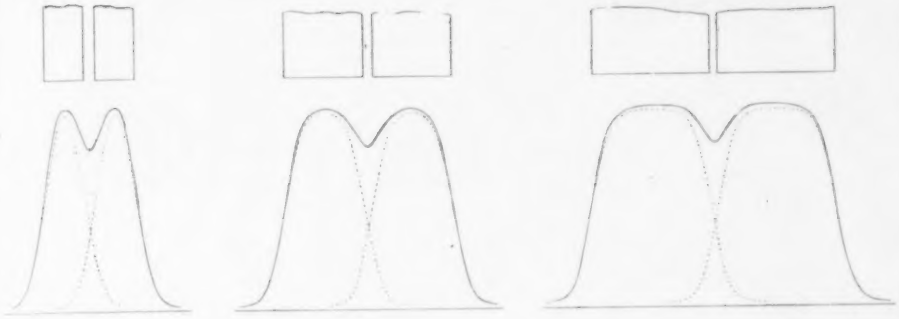

Fig. 1.

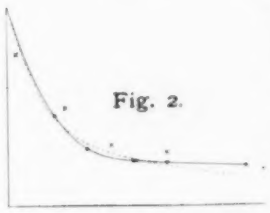

Fig. 2.

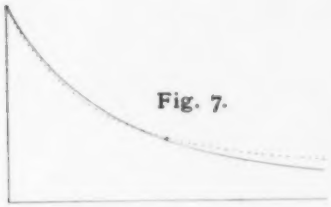

Fig. 7.

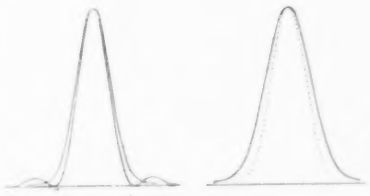

Fig. 3.

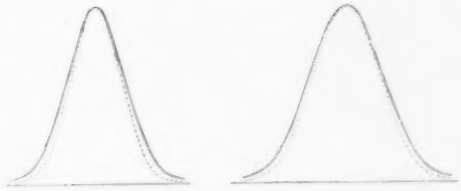

Fig. 4.

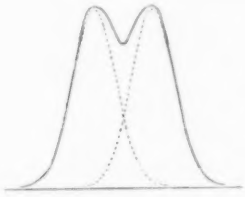

Fig. 5.

Fig. 6.

lines and the angular distance δ between the contiguous edges necessary for distinct resolution, was plotted.

In order to test these results experimentally a fine black wire was stretched across the center of an ordinary double motion slit, thus forming two parallel slits whose widths could be simultaneously varied (by opening the slit), while the distance between the contiguous edges (which was equal to the diameter of the wire) remained constant. The two slits were uniformly illuminated by the light of an electric arc passing through a screen of white paper; and viewed by a telescope over whose objective was placed a rectangular opening whose width, at right angles to the length of the two slits, could be varied.

The slits were set at various measured widths and the aperture in front of the telescope varied until the two slits were just "resolved." The aperture necessary for resolution when the slits were infinitely narrow, would evidently be:

$$A = \frac{\lambda}{\alpha},$$

where α is the angular diameter of the wire as seen in the telescope. For slits of finite width σ, the aperture a' required for resolution was less, and the ratio $\frac{A}{a'}$ measures the ratio of the resolving power of the full aperture A to the angular separation of the two edges necessary to obtain resolution with the same aperture, when the lines have a width σ. In the case of these experiments, the angular width of the wire was about 0.000018 or not quite 4″. Hence A was about 33^{mm}.

The results are presented in the following table:

TABLE I.

σ	a'	$\frac{\sigma}{\alpha}$	$\frac{a'}{A} = \frac{\delta}{\alpha}$
0″.36 (?)	25^{mm}–28^{mm}	0.10 (?)	0.75–0.82
2 .7	17^{mm}	0.75	0.51
4 .7	11	1.30	0.33
7 .2	9	2.00	0.27
11 .7	6	3.25	0.18
16 .2	5	4.5	0.15

For comparison with theory the first five results are plotted in Fig. 2. The agreement with the theoretical curve is as good as could have been expected under the conditions of observation. There was a great deal of vibration of the building at the time, and the light was also unsatisfactory; both of these causes tended to confuse the two images, and therefore to prevent distinct resolution with as narrow an aperture as might otherwise have been used.

The curve of Fig. 2 may up to the point $\sigma = 3a$ be closely represented by the hyperbola of the form, (see dotted curve),

$$\frac{\sigma}{a} + \tfrac{1}{2} = \frac{1}{2\left(\frac{\delta}{a}\right)},$$

whence we get:

$$\delta = \frac{a^2}{2\sigma + a}.$$

But $\sigma = \frac{s}{f}$ and $a = \frac{\lambda}{a'}$ (for rectangular aperture $m = 1$). Substituting these values we have:

$$\delta = \frac{1}{a'} \frac{\lambda^2}{2s\psi + \lambda}. \qquad (5)$$

The angular distance between two lines of width σ which can just be resolved is then:

$$\Sigma = \sigma + \delta = \frac{1}{a'}\left(s\psi + \frac{\lambda}{2s\psi + \lambda}\lambda\right), \qquad (6)$$

instead of $\frac{1}{a'}(s\psi + \lambda)$, as ordinarily given. The difference between this last expression and (6) will amount, in the case of small values of $s\psi$, to over 50 per cent. This point will be considered more in detail in the application of these results to the theory of the spectroscope.

Photographically, only those lines will be resolved for which the distance $\sigma + \delta$ is equal to or exceeds $\frac{ne}{f}$ or $\frac{ne\beta}{a'}$. Hence, if we call Σ_v the photographic resolution for wide lines, we will have:

for
$$\left(s\psi + \frac{\lambda}{2s\psi + \lambda}\lambda \right) \overline{>} ne\beta$$
$$\Sigma = \Sigma_q ; \qquad (7)$$

or, to put it in another way, when the focal length of the camera is such that the quotient of n times the diameter of the silver grain by the focal length is equal to or less than the angular separation necessary for visual resolution, all of those lines which can be visually resolved, will also be photographically resolved. But when

$$\left(s\psi + \frac{\lambda}{2s\psi + \lambda}\lambda \right) < ne\beta,$$

then
$$\frac{\Sigma_q}{\Sigma} = \frac{ne\beta}{s\psi + \frac{\lambda}{2s\psi + \lambda}\lambda} \qquad (8)$$

or
$$\Sigma_q = \frac{ne\beta}{s\psi + \frac{\lambda}{2s\psi + \lambda}\lambda}\,\Sigma = \frac{ne\beta}{a'}$$

as before.

As the width of the lines s becomes greater, the photographic resolution of the camera objective becomes more and more nearly equal to the visual resolution for all focal lengths. In order that the photographic resolution shall be equal to the visual for fine lines, we must have from (1) and (2)

$$\beta = \frac{\lambda}{ne}. \qquad (9)$$

In the preceding paper it was shown that n should be at least 4, in order to ensure photographic resolution under all conditions. Under favorable conditions we might have distinct resolution if n were 3, but there could hardly be definite and assured separation of the photographic images if the number were less than this.

Hence, for the limiting values of β we have

$$\frac{\lambda}{4e} < \beta < \frac{\lambda}{3e},$$

or the angular aperture of the camera objective ought not to be

greater than one-third the ratio between the wave-length of light and the diameter of the silver grain. If we assume for e the value found by Holden for the plates used for lunar photography at Lick Observatory,[1] we find for β:

For $\lambda = 5893$ and $n = 3$. $\beta = 0.039$, or the focal length should be about 26 times the aperture.

For $\lambda = 3970$ (H) (which is near the maximum of photographic action), and $n = 3$. $\beta = 0.026$, or the focal length should be about 40 times the aperture.

In an ordinary rapid dry plate, the diameter of the grains is considerably larger than that given above; on the most rapid plates from two to three times as large. Mr. Newall's measurements give, for the *distance between centers* of the reduced grains, results varying from $0^{mm}.01$ to $0^{mm}.035$ or on the average about $0^{mm}.025$. But, as previously stated, I have found that in those portions of the negative which are of average density the reduced silver grains are separated by about their own diameter, only every alternate grain being on the average affected. The *diameter* of the grains on Mr. Newall's plates will, therefore, be, on this assumption, about that stated above, or from $0^{mm}.01$ to .015.

For grains of this size the angular aperture of the camera objective requisite to give the maximum of photographic resolution, would, for the two cases considered above, be respectively:

For $\lambda = 5893$. $\beta = 0.019$ to 0.013, or the focal length should be from 50 to 75 times the aperture. For $\lambda = 3970$. $\beta = 0.013$ to 0.009; focal length from 75 to 110 times the aperture. For $n = 4$, all of these ratios of focal length to aperture are increased one-third.

Under the most favorable conditions, then, the focal length of the camera should not be less than about 40 times the aperture (since the maximum of photographic action on an ordinary plate lies near the H line), if the finest details of an object are to be photographically reproduced. It is interesting to note that this is very nearly the ratio adopted by Rowland for his concave

[1] *Pub. of the Lick Observatory*, 3, 12.

gratings (43 to 1). Usually the resolution on the photographic plate is not quite equal to the visual resolution of this instrument under similar conditions of use. On the other hand, the above considerations show that there is no advantage in making the focal length greater than about 100 times the aperture, except under the most unfavorable conditions; and that, so far as photographic definition and resolution are concerned, it would be absurd to make it several hundréd times the aperture, as has been sometimes proposed. Indeed the theoretical advantage gained in making it even 100 times the aperture may be more than compensated by the increased haziness resulting from the necessary increase in exposure time. In the case of the recent Lick Observatory photographs of the Moon (which were taken with the 36-inch stopped down to 8 inches), the ratio of focal length to aperture was about 75 to 1. With plates of the grain used by Professor Holden, this is about twice as large as would be necessary to photographically resolve all the details that could be resolved with this aperture. If, then, the focal length had been shortened by one-half just as good results ought to have been obtained; even better, for the exposure time would have been only one-fourth that required with the instrument as actually used. Lest I be misunderstood, let me say that although under *perfect* conditions, the same result would be reached by doubling the linear aperture (the focal length remaining constant), this would, by no means, be true under the practical conditions which exist in lunar and, in fact, celestial photography in general—since owing to a number of causes (of which the most important are the atmospheric disturbances), the use of large linear apertures has inherent difficulties of its own, which it will be extremely difficult, if not impossible, to ever overcome.

If our purpose is to photographically resolve only those details of an object, which have an angular separation Σ (say a series of uniform, bright lines having a width s), then we may with advantage increase the angular aperture of the camera until (see 7 and 8) we have

$$\beta = \frac{s\psi + \frac{\lambda}{2s\psi + \lambda}\lambda}{n\epsilon}, \qquad (10)$$

where, as before, n varies from 3 to 4.

Under these conditions, we would still photographically resolve all the details that could be visually resolved. Suppose for example, $s = 0^{mm}.01$ and $\psi = \frac{a'}{f} = \frac{1}{10}$, *i. e.*, the line is ten times the diameter of the objective from the latter. Then $s\psi = 0.001$ and

$$\left.\begin{aligned} \beta &= 0.076 \text{ or } \frac{f'}{a'} \backsimeq 13 \text{ for } \lambda = 5896 \\ \beta &= 0.071 \text{ or } \frac{f'}{a'} \backsimeq 14 \text{ for } \lambda = 3970 \end{aligned}\right\} \begin{aligned} n &= 3 \\ \epsilon &= .005 \end{aligned}$$

For $\epsilon = 0^{mm}.01$ to $0^{mm}.015$, the ratios of focal length to aperture will range from 27 to 43 for $n = 3$; and from 36 to 54 for $n = 4$.

This last case, that of photographic resolution of lines of finite width, is the one which we meet with in the spectrograph, in which the object photographed is the spectral image of the slit of width s. Here we are concerned not only with the photographic resolution but with the brightness of the spectrum, since upon this latter characteristic will depend the time of exposure, which is quite as important in determining the final goodness of the result as the photographic resolving power.

In order to determine the most advantageous aperture to employ in the various cases which may arise (stellar spectrography, solar spectrography and planetary and nebular spectrography), it is now necessary to consider the relation between the photographic resolution of the spectroscope train *as a whole* and the resulting brightness of spectrum. The spectroscope train may be looked upon simply as a means of producing a series of monochromatic (or nearly monochromatic) images of a single source, the slit of the spectroscope, and of these images, it is evident that only those will be "resolved", or separated, for which the difference in angular dispersion is equal to or greater than the cor-

responding angular resolution a or Σ of the camera objective. In the case of spectral images of a slit this width is a function of two quantities; (1) the width of the slit s, (2) the dispersion of the spectroscope train, which for radiations not monochromatic produces the same effect as a widening of the slit. Theoretically we should distinguish between four cases:

1. The resolving power (theoretical) of a spectroscope train for an infinitely narrow slit and monochromatic radiations, *i. e.*, infinitely narrow spectral lines. This is the quantity usually denoted by r (for visual resolution).

2. The resolving power (also theoretical) for a wide slit and monochromatic radiations. Usually denoted by p, the "purity" of the spectrum.

3. The resolving power (theoretical) for an infinitely narrow slit, but for lines of finite width $\Delta\lambda$. This quantity we will denote by R (visual resolution).

4. The resolving power (practical) for a wide slit and non-monochromatic radiations, ranging for each line over a small value $\Delta\lambda$ as in (3). The practical visual resolving power we will denote by P; and the corresponding photographic resolution by Q. They represent the practical visual and photographic purity of the spectrum.

Let $D = \frac{d\theta}{d\lambda}$ be the angular dispersion of the spectroscope train. The spectroscopic resolution for any case is defined by the ratio $\frac{\lambda}{d\lambda}$, where $d\lambda$ is the difference in wave-length of two lines of mean wave-length, λ, that are just resolved. Therefore for the first case

$$\frac{d\theta}{d\lambda}(d\lambda)_1 = a = m\frac{\lambda}{a'}$$

$$\text{or } r = \frac{Da'}{m}; \qquad (11)$$

a perfectly general relation which holds good whatever may be the nature, form or arrangement of the spectroscope train.

For the second case

$$\frac{d\theta}{d\lambda}(d\lambda)_2 = \Sigma = \frac{1}{a'}\left(s\psi + \frac{\lambda}{2s\psi+\lambda}\lambda\right)$$

$$\text{or } \frac{\lambda}{(d\lambda)_2} = p = \frac{\lambda}{s\psi + \frac{\lambda}{2s\psi+\lambda}\lambda} = r, \qquad (12)$$

which differs from the expression ordinarily given for the purity of a spectrum by the presence of the factor $\frac{\lambda}{2s\psi+\lambda}$ as a coefficient of the second term of the denominator. The existence of this factor necessitates a considerable modification of certain statements based on the old formula for purity. For example, Schuster in his remarks on the practical purity of a bright line spectrum in the article "Spectroscopy," (*Enc. Brit.* **22,** 374) says: "The maximum illumination for any line is obtained when the angular width of the slit is equal to the angle subtended by one wave-length at a distance equal to the collimator aperture. In that case $s\psi = \lambda$ and the purity is half the resolving power. Hence when light is a consideration we shall not as a rule realize more than half the resolving power of the spectroscope." Equation (12) shows however that under this condition for maximum illumination[1] the purity is really 75 per cent. of the theoretical resolving power instead of 50 per cent. as indicated by Schuster. A similar erroneous conclusion (based upon the commonly accepted formula for purity) was drawn by the writer in one of his earlier papers,[2] in which it was stated that the purity in the case of stellar spectra could never exceed one-third the theoretical resolving power (unless the slit width is made less than the diameter of the diffraction image of the star). Equation (12) shows us that this limit should be nearly one-half instead of one-third.

Third case. If the radiation is not monochromatic, but is made up of wave-lengths ranging over an interval from λ to $\lambda + \Delta\lambda$, the dispersion of the spectroscope train will spread out the

[1] As I have previously shown this condition holds only for absolutely monochromatic sources of radiation. *Ap. J.*, January 1895, pp. 62, 63.

[2] *Ap. J.*, January 1895, pp. 68, 69.

image of an infinitely narrow slit into a band in which the distribution of intensity (supposing the dispersion over the small range $\Delta\lambda$ to be strictly proportional to λ) will be the same as in the source of radiation.

This image will be further broadened by diffraction, and the distribution of intensity in the image formed by the camera objective will be given by an expression similar to (4), but containing a term $f(\phi)$, which represents the distribution of intensity in the source of radiation.

The law of distribution (in a normal source) is not yet definitely known. The one ordinarily assumed is that which follows from Maxwell's kinetic theory, which is[1]

$$f(\phi) = e^{-\kappa\phi^2} \tag{13}$$

where κ is a constant whose value varies with the substance emitting radiation and with the temperature and pressure in the source. A law of distribution more recently proposed by Michelson, is[2]

$$f(\phi) = e\frac{\sin^2 r\phi}{\phi^2}. \tag{14}$$

If the first law is assumed we, have for the intensity in the diffraction pattern

$$I_1 = \int_{-\infty}^{+\infty} e^{-\kappa\phi^2} \frac{\sin^2\frac{\pi}{a}(\gamma-\phi)}{\left[\frac{\pi}{a}(\gamma-\phi)\right]^2} d\phi = \psi_1(\kappa, \gamma, a_1); \tag{15}$$

and if the second

$$I_2 = \int_{-\infty}^{+\infty} \frac{\sin^2 r\phi \sin^2\frac{\pi}{a}(\gamma-\phi)}{\phi^2\left[\frac{\pi}{a}(\gamma-\phi)\right]^2} d\phi = \psi_2(r, \gamma, a). \tag{16}$$

I have not succeeded in integrating either of these integrals in finite form. They may be integrated by developing into a series, but I have found it quicker and easier to integrate by mechan-

[1] See Rayleigh, *Phil. Mag.*, April 1889, p. 298, also Michelson, *Phil. Mag.*, September 1892.

[2] *Ap. J.*, November 1895, p. 251.

cal quadrature. Owing to the very close correspondence between the curves represented by (13) and (14) (see Fig. 3), the result will be practically the same whichever law be adopted. The expression for I_1 (15), is one which has actually been integrated and the resulting curves $\psi_1(\kappa, \gamma, a)$ for three values of κ are given in Fig. 4. The dotted lines represent the curves $f(\phi)$ and the full lines the resulting diffraction pattern $\psi_1(\gamma)$.

For convenience the values of κ are expressed in terms of δ, the "half width" of the line (Michelson) and a, the limiting resolving power of the camera objective. The "half width" δ is defined to be the value of ϕ for which $f(\phi) = \frac{1}{2}$. Hence

$$\kappa = \frac{\text{nap} \log 2}{\delta^2}. \qquad (17)$$

What we may call the effective width of the line w is the width $a\,b$, Fig. 3, which is equal to 4δ. At the points a and b the intensity $f(\phi)$ is only about one-twentieth the intensity at the center, and the part of the curve beyond this point may therefore be considered as having but little effect either on the eye or on the photographic plate.

The values of w in the curves of Fig. 4 are $w = a$, $w = 2a$, $w = 3a$.

In Fig. 5 the diffraction curve for a double source, of which each component is of width $w = a$, is shown. Adopting the same rule as before, *i. e.*, that for resolution the intensity at the middle of the diffraction pattern must not be more than 0.8 the intensity at the two maxima on each side, we find that for resolution the distance between the components in different cases must be

$$\begin{aligned} w &= a \quad \text{dist.} = 1.12a = \Omega_1 \\ w &= 2a \quad \text{“} = 1.45a = \Omega_2 \\ w &= 3a \quad \text{“} = 1.90a = \Omega_3 \\ w &= 4a \quad \text{“} = 2.45a = \Omega_4 \end{aligned}$$

For lines so wide that the broadening by diffraction can be entirely neglected we find (Fig. 6) that the distance between the components necessary for resolution is

$$2.3\delta = .575\,w = \tfrac{4}{7}\,w.$$

Expressing the preceding results in the form

$$\Omega = \tfrac{4}{7}\,w + f(w)\,a$$

we have

$$\text{for } w = 0 \qquad f(w) = 1.00 \qquad \Omega = a = \frac{\lambda}{a'},$$

$$\text{for } w = a \qquad f(w) = 0.55 \qquad \Omega = \tfrac{4}{7} w + 0.53 \frac{\lambda}{a'},$$

$$\text{for } w = 2a \qquad f(w) = 0.31 \qquad \Omega = \tfrac{4}{7} w + 0.31 \frac{\lambda}{a'},$$

$$\text{for } w = 3a \qquad f(w) = 0.18 \qquad \Omega = \tfrac{4}{7} w + 0.20 \frac{\lambda}{a'},$$

$$\text{for } w = 4a \qquad f(w) = 0.15 \qquad \Omega = \tfrac{4}{7} w + 0.15 \frac{\lambda}{a'},$$

$$\text{for } w = \infty a \qquad f(w) = 0 \qquad \Omega = \tfrac{4}{7} w + 0.00 \frac{\lambda}{a'}.$$

The coefficients $f(w)$ of the last term are plotted in Fig. 7 as a function of w. The first portion of this curve may, as in the case of Fig. 2, be closely represented by an empirical hyperbola (dotted curve), whose equation is

$$\frac{w}{a} + 1 = \frac{1}{f(w)} \text{ or } f(w) = \frac{a}{w + a},$$

whence

$$\Omega = \tfrac{4}{7} w + \frac{a^2}{w + a}.$$

The angular width of the line ω, since this is produced by the dispersion of the spectroscope train, is

$$\omega = D\Delta\lambda,$$

$$\therefore \Omega = \frac{1}{a'} \left(\tfrac{4}{7} r\Delta\lambda + \frac{\lambda}{r\Delta\lambda + \lambda} \lambda \right); \qquad (18)$$

and therefore for the spectroscopic resolution

$$\frac{d\theta}{d\lambda} (d\lambda)_3 = \Omega,$$

and

$$R = \frac{\lambda}{(d\lambda)_3} = \frac{\lambda}{\tfrac{4}{7} r\Delta\lambda + \dfrac{\lambda}{r\Delta\lambda + \lambda} \lambda} r, \qquad (19)$$

a formula very similar in form to that derived for the purity p in the case of a wide slit and monochromatic radiation.

Fourth case. In order to determine the limit of resolution or the practical purity P in this, the most important case, we must first determine the diffraction curve resulting from a

superposition of all the elements of the slit. If as before these elements are equal in intensity, *i. e.*, if the illumination over the whole width of the slit is uniform, the intensity curve of the diffraction image will be

$$I_{11} = \int_{-\frac{\sigma}{2}}^{+\frac{\sigma}{2}} \psi_1(\xi - \gamma, w, a)\, d\xi = \psi_{11}(\sigma, \gamma, w, a)\,, \tag{20}$$

where

$$\psi_1(\gamma, w, a) = \int_{-\infty}^{+\infty} -\left(\frac{2\phi}{w}\right)^2 \frac{\sin^2 \frac{\pi}{a}(\gamma - \phi)}{\left[\frac{\pi}{a}(\gamma - \phi)\right]^2} d\phi\,, \tag{15$_a$}$$

as derived from (15) and (17).

Since the function ψ_1 itself is not known in finite terms ψ_{11} can not be directly found. We may however approximate very closely indeed to it by replacing the function ψ_1 by the function

$$\frac{\sin^2 \frac{\pi}{\Omega}\gamma}{\left(\frac{\pi}{\Omega}\gamma\right)^2}, \tag{21}$$

which up to the point $\gamma = \frac{\Omega}{2}$, or over all that part of the curve which is important in determining the limits of resolution of a double line, coincides almost exactly with the curve $\psi_1(\kappa, \gamma, a)$.

The expression for I_{11} then becomes

$$I_{11} = \int_{-\frac{\sigma}{2}}^{\frac{\sigma}{2}} \frac{\sin^2 \frac{\pi}{\Omega}(\xi - \gamma)}{\left[\frac{\pi}{\Omega}(\xi - \gamma)\right]^2} d\xi\,, \tag{22}$$

which is exactly similar in form to (4), the only difference being that a has been replaced by Ω.

We may therefore obtain at once the limit of resolution for this case from (6) by replacing a by Ω, giving us

$$\text{limiting angular resolution} = \sigma + \frac{\Omega^2}{2\sigma + \Omega}.$$

Replacing σ and Ω by their values in terms of s, ψ, R, r and λ and reducing we finally obtain as the limiting angular resolution, which we will call as before Σ,

$$\Sigma = \frac{1}{a'}\left[s\psi + \frac{\left(\lambda \frac{r}{R}\right)^2}{2s\psi + \lambda\left(\frac{r}{R}\right)} \right] \tag{23}$$

and for purity

$$P = \frac{\lambda}{(d\lambda)_s} = \frac{\lambda}{s\psi + \frac{\lambda\left(\frac{r}{R}\right)}{2s\psi + \lambda\left(\frac{r}{R}\right)}\left(\frac{r}{R}\right)\lambda} r. \tag{24}$$

This expression differs from (12) only in the presence of the factor $\frac{r}{R}$ as a coefficient of λ in the denominator.

The value of this ratio is greater (and P therefore smaller) as the width $\Delta\lambda$ of the line increases.

For a width $\Delta\lambda = 0.2$ tenth-meters (about the width of some of the lines of the solar prominences), and a resolving power of 25,000 units (a very common power)

$$r\Delta\lambda = 0.0005 \backsimeq \lambda$$

and

$$\frac{r}{R} \backsimeq \tfrac{4}{7} + \tfrac{1}{2} = 1.07.$$

In such cases, where the total width of the spectral image of the line is not greater than the half width of the diffraction image, the term $\frac{r}{R}$ may be taken to be equal to unity without sensible error. But in many cases the width of the line is much greater than this. For a resolving power of 150,000, for example, (such as is frequently employed in solar work), $r\Delta\lambda \backsimeq 6\lambda$ and

$$\frac{r}{R} = \frac{24}{7} + \frac{1}{7} = 3.57.$$

Under these conditions for a width of slit s, such that $s\psi = \lambda$, we have for P

$$\frac{P}{r} = 0.3 \text{ and } \frac{P}{p} = 0.4,$$

or the practical purity is less than one-third the theoretical resolving power for monochromatic radiations and only two-fifths the theoretical purity for such radiations with the same width of slit. By increasing the resolving power of the instrument six times we have only increased the practical purity of the spectrum about two and one-half times. According to the commonly accepted formula for purity this ought to have increased in the same ratio as the resolving power. Conclusions in regard to the purity of the spectrum which have been based upon the old formula are consequently greatly in error for high resolving powers (over 100 per cent. in the case just cited).

For photographic purity we have:

when
$$s\psi + \frac{\lambda^2\left(\frac{r}{R}\right)^2}{2s\psi + \lambda\frac{r}{R}} \geqq n\epsilon\beta$$

then
$$Q = P \qquad (25)$$

and when
$$s\psi + \frac{\lambda^2\left(\frac{r}{R}\right)^2}{2s\psi + \frac{\lambda r}{R}} < n\epsilon\beta,$$

then
$$Q = \frac{s\psi + \frac{\lambda^2\left(\frac{r}{R}\right)^2}{2s\psi + \lambda\left(\frac{r}{R}\right)}}{n\epsilon\beta} P = \frac{\lambda}{n\epsilon\beta} r. \qquad (26)$$

For the brightness of the spectra we have:[1]

(1) For stellar spectra. (Suppose the slit to be at least as wide as the diameter of the first diffraction ring, under which conditions the usual purity of the spectrum is constant and equal to between one-half and one-third (according to the resolving power of the instrument) the visual resolving power of the spectroscope train).

[1] *Ap. J.* January 1895, pp. 68, 69, 72.

a) Continuous spectra

$$i = \tfrac{1}{8}\, k\epsilon\beta^2 A^2 \frac{1}{r\lambda(\lambda_1 - \lambda_2)}. \tag{27}$$

b) Discontinuous (bright line) spectra

$$i = \tfrac{1}{4}\, k\epsilon\beta^2 A^2 \frac{1}{\lambda(2\lambda + \tfrac{1}{8} r\Delta\lambda)}. \tag{28}$$

(2) For spectra from continuous sources (or sources the angular magnitude of whose image is greater than $\frac{s}{f}$), supposing purity constant as before,

a) Continuous spectra

$$i = k\epsilon\beta^2 \frac{s}{r(\lambda_1 - \lambda_2)}. \tag{29}$$

b) Discontinuous spectra

$$i = k\epsilon\beta^2 \frac{1}{1 + \dfrac{2\lambda + r\Delta\lambda}{s}} \backsimeq k\epsilon\beta^2. \tag{30}$$

First case. From an inspection of (28) and (30) we see at once that in the case of bright line spectra there is only one possible way of increasing the brightness *i. e.*, by increasing the angular aperture β of the camera. The photographic purity will be independent of the angular aperture up to the limit imposed by 25) but beyond that we must, in order to maintain the photographic purity constant, increase r in the same ratio as β or make

$$r = \frac{\beta}{\beta_0} r_0, \tag{31}$$

where r_0 is the initial theoretical resolution of the spectroscope train and β_0 is defined by the relation

$$\beta_0 = \frac{s\psi + \dfrac{\lambda^2 \left(\dfrac{r_0}{R_0}\right)^2}{2 s\psi + \lambda\left(\dfrac{r_0}{R_0}\right)}}{ne}. \tag{32}$$

Up to the point $\beta = \beta_0$ the brightness of the spectrum increases in the ratio of β^2; beyond this point it still increases, but less rapidly, because of the increase in r necessary to preserve the photographic purity constant. This increase in r diminishes the

intensity i by reason of an increase in the factor ϵ as well as by reason of the increase in r directly. From (28) we have

$$\frac{i}{i_0} = \frac{\epsilon \beta^2}{\epsilon_0 \beta_0^2} \cdot \frac{6\lambda + r_0 \Delta\lambda}{6\lambda + r\Delta\lambda}, \tag{33}$$

and from (30)

$$\frac{i}{i_0} = \frac{\epsilon \beta^2}{\epsilon_0 \beta_0^2} \cdot \frac{s + 2\lambda + r_0 \Delta\lambda}{s + 2\lambda + r\Delta\lambda}. \tag{34}$$

In both (33) and (34) the terms $r\Delta\lambda$ are, for the usual values of r and $\Delta\lambda$, small in comparison with the terms with which they are associated. Hence in comparing the intensities i and i_0, except for very large values of r_0, we may safely neglect these terms and write

$$\frac{i}{i_0} = \frac{\epsilon}{\epsilon_0} \left(\frac{\beta}{\beta_0}\right)^2. \tag{35}$$

The variation of ϵ, (which is a factor representing the losses by reflection, absorption and diffusion, in the spectroscope train), will vary greatly with the nature of the spectroscope, (grating or prismatic), and with the portion of the spectrum under examination (on account of the varying amount of absorption, diffusion etc., for radiations of different wave-length). Suppose we assume, for the purpose of comparison, that the value of ϵ will vary according to the following law:

for $r = r_0$	$\epsilon =$	.85 (1 prism or 1st order of grating)
for $r = 2r_0$	$\epsilon =$	.72 (2 prisms or 2d order of grating)
for $r = 3r_0$	$\epsilon =$	.60 (3 prisms or 3d order of grating)
for $r = 4r_0$	$\epsilon =$	.50 (4 prisms or 4th order of grating)
for $r = 5r_0$	$\epsilon =$	.45 (5 prisms or 5th order of grating)

which represents approximately the percentage amount of sodium light transmitted through 1, 2, 3, 4, 5 ordinary flint glass prisms. In the case of the grating the variation might be greater or less or even reversed on account of the anomalies of the grating.

Assuming the above law of variation for ϵ and assuming further that $\psi = \frac{1}{10}$ and $r_0 = 25000$ (very common values for ordinary spectrographs), the values of r and $\frac{i}{i_0}$ have been calculated for values of β ranging from one-fiftieth to one-fifth for three different widths of slit; *i.e.* $= s = 0^{mm}.01$, $0^{mm}.02$ and $0^{mm}.03$.

In this calculation the ratio $\frac{r}{R}$ has been taken as 1.1 (which makes $\Delta\lambda$ about 0.2 tenth meter); ne as $0^{mm}.04$ ($e = 0^{mm}.01$ and $n = 4$); and λ as $0^{mm}.0004$ (about the position of maximum photographic action).

TABLE II.

$r_0 = 25{,}000$. Constant Photographic Purity $= Q_0$

β	$s = 0^{mm}.01$ $\beta = 3\frac{1}{3}\cdot 4$ $Q = 9350$			$s = 0^{mm}.02$ $\beta = 1\frac{2}{3}\cdot 6$ $Q = 4900$			$s = 0^{mm}.03$ $\beta = 1\frac{1}{3}\cdot 2$ $Q = 3300$		
	r	$\frac{\epsilon}{\epsilon_0}$	$\frac{i}{i_0}\times\left(\frac{\beta}{0.02}\right)^{2*}$	r	$\frac{\epsilon}{\epsilon_0}$	$\frac{i}{i_0}\times\left(\frac{\beta}{0.02}\right)^{2*}$	r	$\frac{\epsilon}{\epsilon_0}$	$\frac{i}{i_0}\times\left(\frac{\beta}{0.02}\right)^{2*}$
$\frac{1}{50} = 0.02$	25000	1.00	1.00	25000	1.00	1.00	25000	1.00	1.00
$\frac{1}{40}$	25000	1.00	1.56	25000	1.00	1.56	25000	1.00	1.56
$\frac{1}{30}$	31250	.96	2.67	25000	1.00	2.78	25000	1.00	2.78
$\frac{1}{25}$	46750	.87	5.44	25000	1.00	6.25	25000	1.00	6.25
$\frac{1}{15}$	93500	.63(?)	15.75(?)	49000	.84	21.00	33000	.96	24.00
$\frac{1}{8}$	187000	.30(?)	30.00(?)	98000	.59(?)	59.00(?)	66000	.76	76.00

[* The factor $\left(\frac{\beta}{0.02}\right)^2$ is introduced in order to make the ratio $\frac{i}{i_0} = 1$ for $\beta = \frac{1}{50}$.]

Let us consider one of the practical cases cited by Mr. Newall, *i.e.*, that of photographing the bright lines of α Orionis. With a slit width of $0^{mm}.02$ and the telephoto lens of the Cambridge spectrograph (equivalent focal length of 20 times the aperture), 40 minutes exposure was required. If the angular aperture had been increased to one-tenth, and the resolving power r increased in the ratio $\frac{40000}{25000}$, or about two to one, the same degree of photographic purity would have been secured, and the time of exposure diminished in the ratio $\frac{i_0}{i} = \frac{21}{6.25}$, or over three and one-third times. The advantage of the short focal lengths in such a case as this are very evident. With a still wider slit the advantage would be even more marked, with a narrower one somewhat less. In the case of very narrow slits the increase in brightness is less than is indicated in the table, because of the neglect of the term $r\Delta\lambda$ in the denominator of equations (33) and (34). In the case of the largest value of r, ($r = 187{,}000$ or about $7r_0$), the calculated brightness is reduced about 20 per cent. in the case of spectra from extended sources, (34), and nearly 50 per cent. in the case of stellar

spectra, (33), by taking account of this term. In the case of a slit width of $0^{mm}.01$ or less, it would not therefore be advantageous to increase the angular aperture β beyond one-tenth at the most.

Second case. Continuous spectra from extended sources. From (29) we see that in this case the intensity varies directly as β^2 and inversely as r. For two values of β we have from (29)

$$\frac{i}{i_0} = \frac{\epsilon}{\epsilon_0} \frac{\beta^2}{\beta_0^2} \frac{r_0}{r}.$$

Up to the point $\beta = \beta_0$, as defined by (25) or (32), the photographic purity remains constant for a given value of $r = r_0$ and the intensity therefore increases directly as β^2. But beyond this point we must, in order to maintain photographic purity constant, increase the resolving power in the ratio $\frac{\beta}{\beta_0}$. Hence for values of $\beta > \beta_0$ we have

$$\frac{i}{i_0} = \frac{\epsilon}{\epsilon_0} \frac{\beta}{\beta_0}. \qquad (36)$$

The values of $\frac{i}{i_0}$ are therefore the same as given in Table II. for values of β less than β_0. For values of β greater than β_0 they can be found by multiplying the corresponding values in that table by $\frac{\beta_0}{\beta} = \frac{r_0}{r}$. Their values so obtained are given in Table III. The values of β_0, $\frac{\epsilon}{\epsilon_0}$, r_0 and r are the same as before and therefore are not retabulated.

TABLE III.

β	$s = 0^{mm}.01$ $\beta_0 = 5\frac{1}{2}.4$ $\frac{i}{i_0} \times \left(\frac{\beta_0}{0.02}\right)^2$	$s = 0^{mm}.02$ $\beta_0 = 1\frac{1}{4}.8$ $\frac{i}{i_0} \times \left(\frac{\beta_0}{0.02}\right)^2$	$s = 0^{mm}.03$ $\beta_0 = 1\frac{1}{4}.2$ $\frac{i}{i_0} \times \left(\frac{\beta_0}{0.02}\right)^2$
$\frac{1}{50} = 0.02$	1.00	1.00	1.00
$\frac{1}{40}$	1.56	1.56	1.56
$\frac{1}{30}$	2.14	2.78	2.78
$\frac{1}{20}$	2.91	6.25	6.25
$\frac{1}{10}$	4.21	10.72	18.18
$\frac{1}{5}$	4.01	15.05	28.79

From an inspection of these values we see that the advantage of increasing the angular aperture beyond the value β_0 is a good deal less than in the preceding case. Still, in the case of an average slit width $s = 0^{mm}.02$, there is a very considerable gain in making it as large as $\frac{1}{10}$, and if sufficient resolving power is available even as large as $\frac{1}{5}$. Let us again consider a practical case given by Mr. Newall. For a slit width of $0^{mm}.02$ and the telephoto lens, ($\beta = \frac{1}{20}$), 7 minutes exposure was required to photograph the spectrum of Venus with the Bruce spectograph. If the angular aperture had been doubled ($\beta = \frac{1}{10}$) the resolving power would have had to be increased in the ratio $\frac{49}{25}$, in order to obtain the same photographic purity, but the intensity would have been increased in the ratio $\frac{10.72}{6.25}$ or nearly one and three quarter times. The necessary time of exposure then would have been only about 4 minutes. If the aperture had been made still larger, ($\frac{1}{5}$), the intensity would have been increased in the ratio $\frac{6.25}{15.05}$ or about two and one-half times, reducing the time of exposure to about $2\frac{3}{4}$ minutes, but the resolving power r would have had to be increased nearly four times. On the whole therefore it would not be an advantage to make the angular aperture larger than about one-tenth for this width of slit. For wider slits ($s = 0^{mm}.03$) the advantage of the larger angular apertures is greater, but for narrower ones very much less. In the case of slit widths of less than $0^{mm}.01$ (or of very small values of ψ) it may be even a disadvantage to make the angular aperture β any larger than the limiting aperture β_0. Let us consider the case of the concave grating, in which the conditions are somewhat different from those assumed in the calculation of the values in Table II. For the usual form of six-inch concave grating $\psi \backsimeq \frac{1}{40}$ and $r_0 \backsimeq 100000$.

For the same values of $\Delta\lambda$ and λ as assumed before we therefore have from (19)

$$\frac{r}{R} = \frac{87}{35} = 2.5,$$

and for a slit width of $0^{mm}.02$ (about the usual width)

$$\beta_0 = \frac{.0005 + .0005}{.04} = \frac{1}{40}, \qquad \text{from (32)}$$

or about the angular aperture which is actually used in these instruments. We can readily see that in this case there is no gain in making β larger than β_0, because the slight resulting gain in intensity is obtained only at a large increase in resolving power.

(3) *Continuous stellar spectra.* We have last to consider the important case of continuous stellar spectra. In this case the ratio of intensities for two apertures β and β_0 is (from 27)

$$\frac{i}{i_0} = \frac{\epsilon}{\epsilon_0}\left(\frac{\beta}{\beta_0}\right)^2 \frac{r_0}{r},$$

and for constant photographic purity

$$\frac{i}{i_0} = \frac{\epsilon}{\epsilon_0}\left(\frac{\beta}{\beta_0}\right), \qquad (37)$$

where β_0 is defined by (32), as in the preceding case. But what we are directly concerned with in the spectrograph is not the intensity of the spectrum, but the necessary time of exposure. In all of the preceding cases these two qualities have been inversely proportional, but they are not so in the case of stellar spectra. For on account of the insensible width of the spectrum even with the longest focal lengths of the camera objective, it is always necessary to allow the star to drift a certain amount on the slit plate in order to produce a spectrum wide enough for convenient examination and measurement. With a long focus camera the drift necessary to produce a given broadening would be less than with a short focus one, and if the amount of drift is regulated so that in each case the final breadth is the same, then the time of exposure will vary not as $\frac{i_0}{i}$, but as

$$\frac{i_0}{i} \times \frac{\beta}{\beta_0},$$

or

$$\frac{T_0}{T} = \frac{i}{i_0} \times \frac{\beta_0}{\beta} = \frac{\epsilon}{\epsilon_0}. \qquad (38)$$

So that in this case there is an actual increase in the time of

exposure required when the angular aperture is made less than β_0, as defined by (32).

The limiting values of $\beta = \beta_0$ for slit widths of $0^{mm}.01$, $0^{mm}.02$, and $0^{mm}.03$ have already been calculated on the assumption that ϵ, the diameter of the silver grains, is $0^{mm}.01$. But in stellar spectrographic work the extreme faintness of the spectrum makes it necessary to employ, at least for the fainter stars, the most rapid plates obtainable. For with a given degree of photographic purity and a given resolution, the focal length of the camera will increase directly with the diameter of the silver grain ϵ and the intensity will therefore diminish as ϵ^2. But the sensitiveness of the plate increases more rapidly (in general) than the square of the diameter of the grain, and it is therefore advantageous to employ the most rapid plates with long focus camera objectives rather than slower plates and shorter focal lengths.

For the larger values of ϵ ($0^{mm}.015$) and the same values of r_0 and R_0 as before, we have for β_0,

			For $\epsilon = 0^{mm}.015$	For $\epsilon = 0^{mm}.01$
For	$s = 0^{mm}.01$, $\psi = \frac{1}{10}$ $s = 0^{mm}.015$, $\psi = \frac{1}{15}$	$s\psi = 0.001$	$\beta_0 = \frac{1}{56}$	$\beta_0 = \frac{1}{37.4}$
For	$s = 0^{mm}.015$, $\psi = \frac{1}{10}$ $s = 0^{mm}.023$, $\psi = \frac{1}{15}$	$s\psi = 0.0015$	$\beta_0 = \frac{1}{38.7}$	$\beta_0 = \frac{1}{25.8}$
For	$s = 0^{mm}.02$, $\psi = \frac{1}{10}$ $s = 0^{mm}.03$, $\psi = \frac{1}{15}$	$s\psi = 0.002$	$\beta_0 = \frac{1}{29.4}$	$\beta_0 = \frac{1}{19.6}$
For	$s = 0^{mm}.03$, $\psi = \frac{1}{10}$ $s = 0^{mm}.045$, $\psi = \frac{1}{15}$	$s\psi = 0.003$	$\beta_0 = \frac{1}{19.8}$	$\beta_0 = \frac{1}{13.2}$

In the case of stellar spectra the width of the slit is (theoretically) determined by the diameter of the first diffraction ring of the star image, and this in the case of most telescopes will not exceed $0^{mm}.01$ to $0^{mm}.015$. On account of the unsteadiness of the image due to atmospheric disturbances the width of the slit must, in order to avoid undue loss of light, generally be greater than this (as pointed out by Mr. Newall in his paper on the Bruce spectrograph, and previously by Professor Keeler and by the writer) but we cannot afford in general to make it more than $0^{mm}.02$. For this width of slit the maximum efficient aperture β_0 is about $\frac{1}{30}$ for $\psi = \frac{1}{10}$, and about $\frac{1}{40}$ for $\psi = \frac{1}{15}$.

In general, therefore, the focal length of the camera in the case of the stellar spectrograph should not be less than 30 to 40 times the linear aperture. If the spectrum is too faint and the time of exposure too long with this aperture, the proper remedy is to reduce the resolving power (and hence the linear dispersion) of the spectroscope train until the requisite brightness is attained. The great advantage of this method of procedure is that, for a given photographic result, the whole instrument is made smaller, simpler optically, and what is also important, less expensive, while the whole resolving power is practically utilized. The only disadvantage is the diminution in rigidity likely to be caused by the unusual focal length of the camera objective. This difficulty can however be completly overcome either (1) by diminishing the linear aperature a', the resolving power remaining constant; (2) by adopting one of the "fixed arm" forms which have been described and discussed in previous papers;[1] or (3) by adopting Mr. Newall's plan of using a telephoto lens. For an equivalent focal length of 30 to 40 apertures the last plan would have the disadvantage of greatly restricting the field and either the first or second would seem to be preferable. From the consideration of the relative advantages of small *vs.* large apertures the writer inclines to the first plan (or a combination of the first and second) in the case of the stellar spectrograph, in which the

[1] *Phil. Mag.*, October 1894, 337. *A. and A.*, December 1894, p. 835. *Ap. J.*, March 1895, p. 232, November 1895, p. 264 and December 1895, p. 370.

resolving power is low, and to the second plan in the case of the solar spectroscope. It is to be noted moreover that if the form of the spectroscope remains constant, the actual length of the camera remains constant for all values of β greater than $\beta_\circ$. For in order to maintain the photographic purity constant we must increase r in the ratio $\frac{\beta}{\beta_\circ}$, and therefore for similar instruments the linear aperture a' in the same ratio.

Hence

$$f' = \frac{a'}{\beta} = \frac{a_\circ}{\beta_\circ} = \text{Const.}$$

and the only advantage which the instrument of larger angular aperture has is a better proportion of parts.

It will be noticed that in considering the case of stellar spectra the assumption has been made that the slit image is uniformly bright across its whole width. This is not theoretically the case on account of the falling off in intensity at the edge of the diffraction image of the star. But except under the most exceptional conditions of seeing it is practically true on account of the size of the "tremor disk," as Mr. Newall aptly calls it, which is generally two or three times as large as the diffraction image of the star, and hence as the width of slit which it is thought desirable to use. It may be remarked in this connection that the existence and size of this tremor disk is one of the strongest arguments for that which I have so often before advocated, *i. e.*, the use of reflectors rather than large refractors for stellar spectroscopic work, for it makes the definition of the large object glass of comparatively little moment for this purpose. It seems a pity that the great light-gathering power of the large reflectors now in use should not be utilized in this most important and interesting field of research.

RYERSON PHYSICAL LABORATORY,
The University of Chicago,
February 1896.

ON THE VARIABLE STAR Z HERCULIS.

By N. C. Dunér.

In Vol. XVI, No. 6, of the *Astronomical Journal*, Mr. P. S Yendell has published a quite extensive series of observations of the Algol-type star Z Herculis. Mr. Yendell has also made certain computations relating to its periodicity, but since he has given very little consideration to my paper[1] published in The Astrophysical Journal, April 1895, "On the Periodic Changes of the Variable Star Z Herculis," I deemed it desirable to make a comparison between Mr. Yendell's observations and the ephemeris which I have given on page 289 in the article above referred to. The results were as follows:

I. Even Minima						II. Uneven Minima					
		Greenwich M. T.			*O.* − *C.*			*Greenwich M. T.*			*O.* − *C.*
1895.	July	30^{d}	17^{h}	52^{m}	+22^{m}	1895.	April	23^{d}	19^{h}	36^{m}	(−85^{m})
	Sept	4	16	15	+28		June	14	18	45	+15
	"	8	15	31	− 4		July	28	15	51	−34
	"	20	14	53	− 8		Aug.	5	16	18	+17
	"	24	14	30	−20		"	25	14	56	− 7
							Sept.	2	14	15	−22
							"	10	13	52	−25
							"	22	13	47	+ 5

The mean deviation of these observations (omitting the obviously erroneous one of April 23) from the elements which I computed is therefore as follows:

Even minima - - - - - $O. - C. = + 2^{m}$
Uneven minima - - - - $O. - C. = - 7^{m}$

The agreement may consequently be regarded as complete, and it would be superfluous to repeat the computation until later observations are at hand. In the above comparison, as in the

[1] An error of translation occurs in this paper on p. 286, line 21; for "daylight" read "the time of day."—Ed.

original computation, the reduction to the Sun has been neglected.

The observations of Mr. Yendell afford a very beautiful confirmation of the general correctness of my theory, which is all the more valuable since the circumstance that Mr. Yendell in observing used not my ephemeris, but Professor Hartwig's, proves that his observations were in no manner influenced by my computations. In only one particular do the observations of Mr. Yendell seem to conflict with my theory. According to Mr. Yendell the magnitudes of the stars were as follows:

At principal minimum - - - - - -	$7^m.94$
At secondary minimum - - - - -	7 .75

The correctness of these figures is refuted by the following observations:

1. By the observations of myself and the assistant at this Observatory, Mr. Östen Bergstrand, supported by the photometric measures of Mr. Lindemann at Pulkowa. The results were:

Brightness at maximum - -	$6^m.89$	(Lindemann)
" at principal minimum	8 .05	(Lindemann)
" at secondary minimum	7 .35	(Dunér and Bergstrand)

2. By the observations of Hartwig in 1894. For if, at the beginning of Hartwig's observations of the secondary minima, the star had not been brighter than $7^m.75$, he could not possibly have arrived at the conclusion that the uneven minima occurred at a time of day so much earlier than the even minima as in fact he made it. If, on the other hand, my values for the brightness of the star at the secondary minimum are taken as correct, Hartwig, since he did not know that the minima differ in brightness, would certainly have been led to the conclusion that the uneven minima began about four hours earlier in the day than the even minima.

3. By the words of Mr. Yendell himself. He says, "The odd or secondary minima were found difficult of observation from the small range of the variation and the indefiniteness of phase." This would be a perfectly correct description of the appearance

if the whole amplitude covered only $6^m.89$ to $7^m.35$. But if the range were $6^m.89$ to $7^m.75$, the minima would be marked and easily observed,—in fact more easily than those of Y Cygni, U Ophiuchi, etc.

I must therefore maintain that my theory is correct in this particular also.

Finally, in order to ascertain when and where the star may be advantageously observed, I have computed the following ephemeris:

Epoch		Even Minima G. M. T.				Epoch		Uneven Minima G. M. T.			
300	1896	May	9^d	3^h	52^m	301	1896	May	11^d	2^h	33^m
350		Aug.	16	23	4	351		Aug.	18	21	45
400		Nov.	24	18	16	401		Nov.	26	16	57
450	1897	Mar.	20	13	28	451	1897	Mar.	22	12	9
500		June	6	8	40	501		June	8	7	21
550		Sept.	14	3	52	551		Sept.	16	2	33
600		Dec.	22	23	4	601		Dec.	24	21	45
650	1898	April	1	18	16	651	1898	April	3	16	57
700		July	10	13	28	701		July	12	12	9
750		Oct	18	8	40	751		Oct.	20	7	21
800	1899	Jan.	26	3	52	801	1899	Jan.	28	2	33

The circumstances are unfavorable. In 1896 the star can be observed only in Australia and Asia; in 1897 only in the eastern part of Europe; in 1898 it can be observed in the eastern part of America, and a part of the uneven minima in western Europe also. The star can probably not be observed under favorable circumstances in central Europe until 1902. It is to be feared, therefore, that this very interesting star will be sadly neglected.

Upsala,
March 4, 1896.

ON THE WAVE-LENGTH OF SOME OF THE HELIUM LINES IN THE VACUUM TUBE AND OF D_3 IN THE SUN.

By J. F. MOHLER and L. E. JEWELL.

THROUGH the kindness of Dr. W. W. Randall and Professor Ira Remsen we obtained the use of a tube filled with pure helium by Professor Ramsay, and have measured the positions of the D_3 lines. We used the second spectrum of a large concave grating ruled with 20,000 lines to the inch and of 21.5 feet radius. The comparison lines for the direct measurements were carefully selected solar lines. Several photographs were also taken and the comparison lines in these cases were principally iron lines in the arc.

As several other helium lines in the ultra-violet appeared on the same plates with D_3 they also were measured. One photograph was taken in the first spectrum with an exposure of three hours, another in the second spectrum with an exposure of five hours, and a third plate was given a two and one-half hours' exposure in the second spectrum. All these plates were taken at night when the building was perfectly quiet; and the definition is excellent, especially in the plate exposed two and one-half hours.

The plates were measured on the dividing engine used in the preparation of Professor Rowland's table of standard wave-lengths.[1] The method of measuring was the same as that used by Messrs. Humphreys and Mohler in their work on the effect of pressure on wave-length.[2]

Table I. gives the results of measurements made on the lines produced in the vacuum tube, the first part being the results of measurements with the eyepiece micrometer using solar lines for

[1] *A. and A.* **12**, 1893; also *Ap. J.* **1**, **2** and **3**.

[2] *Ap. J.* **3**, 118.

comparison. The wave-lengths of these lines are taken from the table of solar spectrum wave-lengths now being published in this JOURNAL by Professor Rowland. The second part of this table gives the result of the measurements of the II spectrum plates. The wave-lengths of the standards used are from the table published by Mr. Jewell in THE ASTROPHYSICAL JOURNAL, February 1896, p. 109. The last part of this table gives the results of the measurements of the I spectrum plate; and the wave-lengths of the standards here used are the means of all the measurements on these lines which were used in the preparation of Professor Rowland's table of standards without any correction having been applied to make them agree with the solar standards.

The observations marked *J* were made by Mr. Jewell and the those marked *M* by Mr. Mohler. Table II. gives the position of the D_3 lines in the chromosphere of the Sun and also in the neighborhood of Sun-spots. A large plane grating of 15,000 lines to the inch was used for this purpose.

Table III. gives the mean values of our measurements and also the values given for the same lines by Runge and Paschen.[1]

Table IV. is a list of all the lines in the solar spectrum in the vicinity of D_3. This table is the result of measurements on several plates of all the lines that can be seen, and differs slightly from the table of this region already published in THE ASTROPHYSICAL JOURNAL. It contains a few more lines and slightly more accurate positions for some of the lines, as a result of additional measurements. This shows lines agreeing fairly well in position with the two components of D_3, but it is probable that both of these lines are due, principally at least, to water-vapor.

The lines produced by the vacuum-tube were sharp and clear both when viewed directly and on the photographic plates, although in both cases the faint component was somewhat difficult to measure. In the chromosphere the lines were diffuse and broad, and the two components not easily separated; consequently the measurements on the faint component are little more than estimates. Directly over Sun-spots the lines were usually

[1] *Ap. J.* 3, January 1896.

faint, but near the spots (probably over the faculæ) the principal component was fairly dark and narrow and the faint component just visible, but too faint to measure, so that the measurements were made on the principal component alone. The two lines used for standards, although small, are sharp and clear and equally distant from D_3. During the two days upon which these measurements were made the air was very dry and the water-vapor lines in the neighborhood almost invisible. The wave-length of the principal component near Sun-spots is *less* than in the chromosphere. This might indicate an uprush of material at these places, or a lowering of pressure; this is the effect that might be expected over prominences. The difference in intensity of the two components of D_3 being so great, measurements upon it as a single line vary according as the cross-hairs of the instrument are set upon the middle of the line or upon the position of maximum intensity, therefore the personal equation of the observer enters quite largely into such determinations of its position. As a consequence of this the results of different observers as published vary greatly, and any such determination must necessarily be unsatisfactory. Mr. A. De F. Palmer in his article on D_3 in the *American Journal of Science*, **5**, 1895, giving the results of his measurements made at the Johns Hopkins University in 1893, claims an accuracy of 0.006 of an Ångström unit. The preceding considerations together with an examination of the original observations made jointly by Mr. Palmer and Mr. W. S. Day show that this claim of extreme accuracy is untenable.

We wish to thank Professor Rowland and Dr. Ames for the use of the instruments and plates used in these measurements, and Professor Remsen and Dr. Randall for the use of the helium tube.

TABLE I.

LINES PRODUCED BY A VACUUM-TUBE CONTAINING HELIUM.

Helium Wave-length	Intensity	Observer	Number of readings	Spectrum	Comparison Lines
D_3 5875.813	5	J.	2	II	5853.902, 5859.809, 5862.582, 5866.675, 5893.097
D_3 5876.148	1	J.	2	II	5905.895, 5916.475, 5919.860, 5930.406, 5934.881
D_3 5875.815	5	J.	2	II	Same as above.
D_3 5876.150	1	J.	2	II	
D_3 5875.812	5	M.	2	II	5853.902, 5859.809, 5862.582, 5866.675,
D_3 5876.153	1	M.	2	II	5905.895, 5916.475, 5919.860, 5930.406.
Ghost 3888.771		M.	2	II	
3888.754	10	M.	2	II	3865.665, 3878.161, 3878.709, 3886.415, 3888.661
3888.851	2	M.	2	II	3903.087, 3905.661, 3920.398, 3923.038, 3928.059
D_3 3875.816	5	M.	2	II	3930.438, 3944.160.
D_3 5876.132	1	M.	2	II	
*3888.656	0	J.	4	II	
Ghosts3888.771		J.	4	II	
3888.758	10	J.	4	II	3886.415, 3888.661, 3903.081, 3905.661,
3888.859	1	J.	4	II	3920.396, 3923.038, 3928.059, 3930.438.
D_3 5875.812	5	J.	4	II	
D_3 5876.151	1	J.		II	
D_3 5876.149	1	J.	8	II	Difference on plate exposed five hours.
D_3 5876.150	1	M.	10	II	
4026.325	3	M.	2	II	4005.399, 4030.900, 4033.213, 4034.631, 4045.964, 4063.751, 4071.896.
4026.500	0	J.	5	II	Difference on plate above.
D_3 5875.802	5	J.	2	I	2912.267, 2929.121, 2937.014, 2947.986, 2954.050,
D_3 5876.146	1	J.	2	I	2957.477, 2965.373, 2970.213, 2981.558, 2983.681.
D_3 5875.802	5	M.	2	I	2912.267, 2929.121, 2937.014, 2997.986,
D_3 5876.130	1	M.	2	I	2973.347, 2983.681.
D_3 5875.814	5	M.	2	I	Same as above.
D_3 5876.146	1	M.	2	I	

*It is uncertain whether this weak line belongs to helium or some impurity.

TABLE II.

POSITION OF THE D_3 LINES IN THE SOLAR SPECTRUM.

Wave-length	Intensity	Observer	Order of spectrum	Number of readings	Position	Comparison Lines
5875.857		J.	II	5	West limb	5873.436, 5878.015
5876.188		J.	II	4	West limb	" "
5875.824		J.	II	5	East limb	" "
5876.175		J.	II	5	East limb	" "
5875.815		J.	II	13	Near Sun-spots	" "

TABLE III.

Mean values for the vacuum tube Jewell and Mohler	Mean value for the chromosphere	Mean value for vicinity of Sun-spots	Values given by Runge and Paschen[1]
3888.766			3888.785
3888.855			
4026.325			4026.342
4026.500			4026.512
D_3 5875.812	D_3 5875.841		5875.870
D_3 5876.147	D_3 5876.182	D_3 5875.815	5876.209

DISTANCE BETWEEN THE COMPONENTS OF D_3.

Runge and Paschen, vacuum tube 0.339. Mohler and Jewell, vacuum tube, 0.335

Hale and Ellerman, solar prominence, 0.357.

TABLE IV.

LINES IN THE VICINITY OF D_3 IN THE SOLAR SPECTRUM.

Wave-length	Substance	Intensity
5875.330	A (wv)	0
5875.425		00000
5875.512		0000
5875.665	A (wv)	00
5875.810	A (wv)	0
5875.970	A (wv) ?	000N
5876.160	A (wv) ?	0000N
5876.340	A (wv)	1
5876.513		00N
5876.660	A (wv)	0
5876.775	A (wv)	000

PHYSICAL LABORATORY, JOHNS HOPKINS UNIVERSITY,
March 12, 1896.

[1] ASTROPHYSICAL JOURNAL, January 1896.

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PRELIMINARY TABLE OF SOLAR SPECTRUM WAVE-LENGTHS. XIII.

By HENRY A. ROWLAND.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
6327.820	Ni	2	6361.031	Ni	0
6327.997		0000	6361.415		0000 N
6329.142	A (O)	000	6362.560	Zn	1
6329.855	A (O)	000	6363.090	Cr, Fe	2
6330.316	Cr	1	6364.575	Fe	1
6331.067	Fe	2	6364.920		0
6331.345		0000	6366.564	Ti	000
6331.619		0000	6366.707	Ni	0
6332.180		0 N	6366.982		0000
6333.460	A (wv)	0000	6367.350		000
6334.588	A (O), (wv?)	0000	6367.640		000
6334.903		0000	6369.244		0000
6335.307	A (O)	0000	6369.683	Fe	0
6335.554	Fe	6	6370.574	Ni	00
6336.032	A (wv)?	0000	6371.573	Fe	1 N d?
6336.329	Ti	000 N	6375.455		0000
6336.665	A?	0000	6376.033		000
6337.048	Fe	7	6376.385		0000
6339.096	Fe	2	6378.468	Ni	2
6339.335	Ni	2	6378.877		0000
6339.520		0000	6379.165		0000
6340.190		0000	6379.878		0000
6342.603	A (wv)	0000	6380.958	Fe	4
6344.030		0000	6381.359		0000
6344.371	Fe	4	6381.844		0000
6347.310		2 N	6383.932		0 N
6347.572		0000 N	6384.119		0000
6348.080		000	6384.886	Ni	1
6350.709		000	6385.303		0000 N
6350.920	A (wv)	0000	6385.680	Mn?	000 N
6351.510		0000	6385.950		0
6352.728		0000	6388.630		000
6353.160		0000	6389.502		0000
6353.602		0000	6390.715		000
6354.060		0000	6391.472		0000 N
6354.868		0000	6392.751		0
6355.246	Fe	4	6393.820 s	Fe	7
6355.410		00	6394.417		000 N
6358.898	Fe	6	6394.700		0000 N
6359.437		0000	6395.378		00 N d?

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
6396.038		0000	6428.385		0000
6396.600		0000 N	6428.843		0000
6397.757		0000	6430.130		000
6398.205		000 N	6430.485		0000
6399.129		0000 N	6430.665		0000
6400.100		000	6431.066 s	Fe	5
6400.217 s	Fe	8	6431.466		0000
6400.538 s	Fe	2	6431.890		0000
6401.023		0000 N	6432.240		000 N
6401.296		0000 N	6432.529		0000
6401.714		0000	6432.895	Fe?	1
6402.507		0000 N	6433.110	A	0000
6403.345		000 N	6433.665	Fe?	0 N
6403.910		0000 N	6433.948		0000
6404.392		0000 N	6434.796	A	0000
6405.980		00 N d?	6435.260		0000
6406.590		0000 N	6436.267		0000
6407.350		0000 N	6436.630	Fe?	0
6407.515		0 N	6437.136		0000 N
6408.233 s	Fe	5	6437.930		000 N
6408.587		0000	6438.251		0000 N
6408.910	Sr?	000	6438.995		000
6409.497		0000	6439.293 s	Ca	8
6410.643		0000	6439.786		0000
6411.145		00	6440.326		0000
6411.330		000	6440.865		0000
6411.865 s	Fe	7	6441.158	Mn?	000
6412.445		0000	6441.835		0000
6413.800		0000 N	6442.693		0000 N
6414.147		0000	6443.180		000
6414.813	Ni	0	6443.700		0000 N
6415.199		1 N	6444.430		0000 N
6415.635		0000 N	6444.880		0000
6416.242		0000	6446.345		0000 N
6416.741		0000	6446.620		0000
6417.133	Fe?	1	6448.170		0000 N
6417.427		0000	6449.355		0 N d?
6417.900	Co	00 N	6449.650		0000 N
6418.095		0000	6450.033 s	Ca	6
6419.585		0000	6450.396	Co	0
6419.880		000	6450.552	Co	0
6420.169 s	Fe	4	6450.866		0000
6420.820		0000	6451.785		000 N
6421.022		0000	6452.536		00 N
6421.570 s	Fe	7	6452.900		0000 N
6421.740	Ni	000	6453.815		0000 N
6425.080		00	6454.350	A	0000 N
6425.748		0000	6455.230	Co	0 N
6426.510		000 N	6455.485		0000 N
6426.900		0000 N	6455.820	Ca	2

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
6456.070		0000	6474.330	A (wv)	000 N
6456.238		0000	6474.830	A?	0000 N
6456.603		3	6475.280	A (wv)	00
6456.872		0000	6475.435	A (wv)	00
6457.080		00 N	6475.846		2
6457.335	A?	0000	6476.046	A (wv)	0
6457.595		000	6476.584		0000
6458.770		0000	6476.795		0000
6459.115	A	000	6477.240		0000
6459.300	A	0000	6477.550	A (wv)	0000 d
6459.904	A	0000	6478.110		000 N
6460.210	A	0000	6479.408	A (wv)	00
6460.440	A	0000	6479.715	A (wv)	000
6461.154	A?	0000	6480.285 s	A (wv)	1
6461.345		0000	6480.475	A (wv)	0000
6462.060	A	0000	6481.220	A (wv)	000 N
6462.260	A	0000	6481.910	A (wv)	0000
6462.784 } s	Ca	5	6482.098		3
6462.965 } s	Fe	3	6482.410		000
6463.188		0000	6482.690		0000
6463.334	A?	0000	6483.027	Ni	1
6463.475	A?	0000	6483.286	A (wv)	0000
6463.715	A (wv)	000	6483.468	A (wv)	1
6463.965	A?	0000	6483.677	A (wv)	0000
6464.170		0000	6483.975	A (wv)	0000 N
6464.398		0000	6484.170	A (wv)	00 N
6464.650	A (wv)	000	6484.694	A (wv)	0000
6464.897		00	6484.900	A (wv)	000
6465.630	A?	0000	6485.120	A (wv)	0000
6466.002		0000	6485.360		0000 N
6466.490	A	000 N	6485.790	A (wv)	00
6466.960	A	000 N	6486.495		0000 N
6467.212		0000	6487.005	A (wv)	0
6467.823	A	0000 N	6487.515	A?	0000
6468.120	A	000	6487.755	A?	0000
6468.590	A?	0000	6488.250	A (wv)	000 N
6469.050		0000	6489.350	A (wv)	00
6469.408		2	6489.870		0000 N
6469.593	A (wv)	0000	6490.595		0000 N
6469.860	A (wv)	000 N	6490.877	A (wv)	0000
6470.210	A (wv)	000 N	6491.015	A (wv)	1
6470.794		0000 N	6491.465		0000 N
6471.118		0000 N	6491.800		1
6471.522		0000	6491.876	Mn	000
6471.885 s	Ca	5	6493.130	A (wv)	0
6472.360		0000 N	6493.480	A (wv)	000
6472.700	A (wv)	00	6494.004 s	Ca	6
6472.823	A?	0000	6494.273		0000
6473.405	A (wv)	00	6494.530	A?	0000
6473.744		0000 N	6494.725	A (wv)	1

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
6495.213 s	Fe	8	6517.925		0000
6495.962		1	6518.245	A (wv)	00
6496.082	A (wv)	2	6518.599 s	Fe?	2
6496.340		0000	6518.973		0 N
6496.688	Fe	2	6519.410	A (wv)	00 N
6497.128	Fe	4	6519.682	A (wv)	1 N
6497.840	A (wv)	00 N d?	6520.350		0000 N
6498.407		0000 N	6520.983		0000 N
6498.654		0000	6522.123	A (wv)	0000
6499.168	Fe	1	6522.430	A (wv)	0000
6499.437		000 N	6523.145		0000 N
6499.880 s	Ca	4	6523.580	A (wv)	0000
6500.122		0000	6523.907	A (wv)	0000
6500.353		0000	6524.080	A (wv)	1
6501.060		0000	6524.968		0000
6501.440		000 N	6526.040	A (wv)	0000
6501.901		0	6526.655		0000
6502.425		0000 N	6526.888		0
6502.747	A	0000	6527.444		1
6503.114	A	0000	6527.825		0000 N
6503.840	A?	0000 N	6528.340		0000 N
6504.415	A (wv),-	0	6528.777		00
6504.700		0000	6529.415		0000 N
6505.053		0000 N	6530.247		0000
6505.710		0000 N	6530.845	A (wv)	00
6506.560		0000 N	6531.311		0000
6507.340		0000 N	6531.667		000
6507.890	A (wv)	0000 N	6532.595 s	A (wv)	1
6508.380		0000	6532.800		0000
6508.826	A (wv)	0	6533.110	Ni?	0
6509.080		00	6533.330		0000
6509.845		000	6533.763		0000 N
6510.410		0000 N	6534.172 s	-,A (wv)	2
6511.679		0000	6534.470		0000
6512.240	A (wv)	00	6534.875	A (wv)	0000
6512.470	A (wv)	00	6535.210		0000
6513.145	A?	0000	6536.212		0000
6513.300		0000	6536.955	A (wv)	00
6513.847	A	0000 N	6537.480		0000
6514.185	A?	0000	6537.666		0000
6514.530	A (wv)	000 N	6538.170		000 Nd?
6514.956	A (wv),-	2	6538.770	A?	000 Nd?
6515.456		0000	6540.665	A?	000 N
6516.080	A (wv)	000	6541.510	A?	0000
6516.311 s		2	6542.550	A (wv)	00
6516.634		0000	6543.280	A?	0000 N
6516.750	A (wv)	1	6544.140	A (wv)	2
6516.855	A (wv)	2	6546.030	A (wv)	000 N
6517.315	A (wv)	0	6546.479 s	Ti-Fe	6
6517.657		0000	6547.945	A (wv)	0

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
6548.855	A (wv)	1	6583.787	A (wv)	0000
6549.290	A?	0000	6583.967		00
6550.515	A?	0000	6584.550	A?	0000
6551.940		000	6584.797	A?	000
6552.275		0000 N	6585.470	A (wv)	0000 N
6552.865 s	A (wv)	1	6585.763	A?	000
6554.025	A (wv)-	00 Nd?	6585.950		0000
6554.470	Ti	0	6586.550	Ni	1
6555.080		0000 N	6586.764	A (wv)	000
6555.700		1 N	6586.935	A (wv)	0000
6556.087		0000	6587.864		00 N
6556.308	Ti, A (wv)	1	6588.828	A (wv)	0000 N
6556.558		0000	6590.245		0000 N
6557.046	Fe?	0	6591.575	Fe?	00
6557.408	A (wv)	0	6591.833		0000
6558.095	A?	0000	6592.076		0000
6558.392	A (wv)	00 N	6592.372		0000
6558.830	A?	0000 N	6592.770	Ni	00
6559.193		0000	6593.161 s	Fe	6
6559.815		0	6594.121 s	Fe	4
6560.045		0000	6594.600	A (wv)	000
6560.307		0000	6595.590		0000
6560.490		0000	6596.135		000 N
6560.800	A (wv)-	1 Nd?	6597.273		0000 N
6561.335		000	6597.807	Cr	1
6563.045 s C [1]	H	40	6598.552		0000 N
6563.763	A (wv)	000	6598.848	Fe?	0
6564.305	A (wv)	00	6599.131		0000
6564.450	A (wv)	0	6599.353	Ti	00
6565.083	A?	0000 N	6599.570	A (wv)	000
6565.783	A?	000	6599.925		0000
6566.075	A?	0000	6602.370	A (wv)	0000Nd?
6569.040	A (wv)	000 N	6603.601		0000 N
6569.460 s	Fe	5	6604.837		1
6570.103		0000 N	6605.810		000
6570.965		0000 Nd?	6606.160		000 N
6571.436		0000	6607.215		00 N
6572.330 s	A (wv)	1	6607.586		0000 N
6573.030	Ca?	1	6608.280		0
6573.765		0000 N	6609.360 s		3
6574.468 s		1	6609.818		00
6574.707		0000	6609.929		000
6575.085 } s	A (wv)	1	6610.315		0000
6575.270 }	Fe	2	6610.990		0000
6576.615		000 Nd?	6611.612		0000
6577.131		0000	6612.474		000
6580.470	A (wv),-	00 N	6612.790		0000
6581.025	A (wv)	00	6613.675		00 N
6581.452		0	6614.045	Ni	00 Nd?
6583.505	A?	0000	6617.267		000 Nd?

[1] The width of C is 0.963; and that of the extreme shading is 1.240. C is either faintly double or reversed in the Sun.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
6617.980		000 N	6657.205		000 N
6618.586		0000 N	6657.878		000
6619.825		000 N	6659.164		0000
6621.441		0000 N	6660.105		000
6622.639		0000 N	6660.830		0000
6624.161		0000 N	6661.320	Cr	00
6624.605		0000 N	6661.580		000
6625.077		0000 N	6662.011		0000 N
6625.276		0	6662.819		0000 N
6626.504		0000	6663.487 s		1
6627.797	Fe?	0	6663.701 s	Fe	3
6628.402		000 N	6664.030		0000 N
6629.210		000 N	6664.550		0000 N
6629.628		0000	6665.420		000 N
6629.924		0000	6665.998		0000
6630.270	Cr	000	6666.780		000 N
6631.325		000 N	6667.695		000
6632.011		0000	6667.980	Fe?	00
6632.267		000	6668.640		000 N
6632.710		00 N	6669.041		0000 N
6633.665		0	6669.550		000 N
6633.995 s	Fe	2	6672.915		0000
6634.361		0	6678.235 s	Fe	5
6635.001		0000 N	6678.817		0000
6635.375	Ni	0 N	6679.090		000 N
6635.636		0000	6680.396		000
6635.940		00 N	6680.864		0000
6636.570		0000 N	6685.131		0000
6638.314		0000	6687.750		0000
6639.505		0000 N	6691.067		000 N
6639.955		0	6692.547		000 N
6640.135		00 N	6693.099		000 N
6642.510		0000 N	6695.886		0000 N
6643.457		0000 Nd?	6696.275		1 N
6643.876 s	Ni	5	6696.565		00
6644.102		0000	6697.070		0000
6644.520		000 N	6697.650		000 N
6645.365		000 N	6698.336		0000 N
6646.309		0000	6698.913		0
6647.205		00	6699.380		00
6648.095		0000	6701.163		0000
6648.360		000	6701.621		000
6648.930		0000	6703.820 s		1
6651.371		0000	6704.286		0000 N
6652.600		0000 N	6704.745		000
6653.215		0000	6705.352 s		1
6654.105		00	6705.753		0000
6654.660		0000	6705.942		0000
6655.770		000 N	6707.695		000
6656.620		0000	6708.176		0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
6709.226		0000 N	6743.826		000 N
6710.182		0000 N	6745.364		00
6710.570		0	6745.798		000 N
6710.789		0000	6746.235		00
6711.529		0000	6747.226		000
6712.094		000 N	6747.812		0000 N
6712.714		000 N	6748.390		000
6713.290		1	6748 686		0000
6713.454		000	6749.029		000
6713.993		1	6749.120		000
6715.635		1	6749.791		0000 N
6716.500		0	6750.033		0000 N
6716.914		000 N	6750.407 s	Fe	3
6717.775		000	6751.690		0000
6717.940 s	Ca	5	6752.965 s	Fe	1
6719.880		000 N	6753.265		000 N
6721.020		0000 N	6753.720		000 N
6722.096 s		2	6754.233		0000
6722.959		0000 N	6755.189		000
6724.935		000 N	6755.855		0
6725.219		0000	6756.818		000 N
6725.615	Fe	0	6757.445		00 Nd?
6725.960		0000	6757.909		0000 N
6726.539		0000	6759.146		000 Nd?
6726.925 s	Fe	2	6761.260		000 Nd?
6728.922		0000	6761.852		0000Nd?
6729.270		00	6762.405		0000 N
6729.996		000 N	6762.647		000
6730.558		000 N	6763.549		0000 N
6732.320		00	6763.939		0000 N
6732.921		0000	6764.330		000 Nd?
6733.410	Fe	1	6767.602		0000Nd?
6733.783		0000 Nd?	6768.028 s	Ni	4
6734 524		000 N	6768.248		0000
6735.277		0000	6769.930		000
6735.708		000 N	6771.310	-, Co	0 d
6736.099		0000 N	6771.789		0000
6736.798		000	6772.152		0000
6737.619		0000 N	6772.568 s	Ni	2
6738.230		0	6775.047		0000 N
6738.485		00	6776.595		0000 N
6739.080		00 N	6777.653		00
6739.370		0000	6778.022		0000 N
6739.775		0	6781.172		0000 N
6740.244		0000	6782.061		0000 N
6741.268		0000	6782.465		000 N
6741.880		0 N	6782.748		0000 N
6742.535		0000	6783.609		0000 N
6742.816		0000 N	6783.960		00
6743.381	Ti	1	6784.460		000 N

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
6785.306		000 N	6820.630 s	Fe	2
6786.010		000 N	6820.987		0000 N
6786.450		0000 N	6822.293		0000 N
6786.706		000 N	6825.108		000 N
6787.100 s	Fe	1	6827.529		0000
6787.850		0000 N	6828.215		000 N
6789.400		000 N	6828.445		0000 N
6789.776		0000	6828.850 s	Fe	2
6790.206		000	6829.293		0000
6790.569		0000	6829.832		0000
6790.933		000	6831.098		0000
6792.577		0000	6831.730		0000
6793.088		0000 N d?	6832.727		0000
6793.520		00	6833.501		00
6793.875		0 N	6833.845		0000 N
6794.219		0000	6835.622		0000 N
6794.560		000	6836.956		0000 N
6794.870		000	6837.268		0
6795.675		000 Nd?	6838.612		0000 N
6796.045		000 N	6838.980		00
6796.375		0	6839.088		0
6796.737		000 N	6840.086		1
6797.061		0000	6840.698		0000 N
6797.410		0000	6841.598 s	Fe	3
6798.715		00	6841.897		0000 N
6799.136		0000 N	6842.294		0
6800.265		0000	6842.624		0000 Nd?
6800.855		00 N	6842.945		1
6801.450		0000 N	6843.420		000 N
6802.097		0000	6843.913 s	Fe	3
6804.102		0000	6844.939		0000
6804.258	Fe	0	6845.937		0000
6804.545	Fe	0	6847.860		000
6805.126		0000	6848.468		0000 N
6805.354		000	6848.823		0 Nd?
6806.000		0000 N	6849.559		000 N
6806.593		0000 N	6850.110		0000 N
6807.103 s	Fe	1	6850.696		00 N
6807.630		0000 Nd?	6851.309		0000 N
6808.141		0000 N	6851.910		000
6809.017		0000 N	6852.980		000
6809.878		0000 N	6854.109		0000
6810.519 s	Fe	3	6854.590		000
6812.605		000 N	6854.796		0000
6813.865		000 Nd?	6855.105		00
6814.160		0000 N	6855.419 s	Fe	3
6815.210	Co	0	6855.700		0000
6817.903		0000	6855.990		0
6819.845		00 Nd?	6856.290		0000
6820.098		000 Nd?	6857.515		0

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
6857.773		0000 N	6875.415		0000 N
6858.109		0000 N	6875.830 s	A (O)	13
6858.415		2	6876.255		000 N
6858.661		0000	6876.595		000 N
6858.863		0000	6876.958 s	A (O)	13
6859.227		0000	6877.440		0000Nd?
6859.752		0000	6877.882 s	A (O)	12
6860.007		000	6878.342		0000 N
6860.358		0000	6878.570		0000Nd?
6860.590		000	6878.800		0000 N
6861.044		0000	6879.288 s	A (O)	12
6861.213		000	6879.528		0000
6861.529		0000	6879.784		000
6861.770	Ti?	000	6880.040		0000
6862.014		0000	6880.172 s	A (O)	6
6862.210		0	6880.455		0000
6862.431		0000 N	6880.887		00
6862.760		1	6881.305		0000 N
6863.119		0000	6881.720		00
6864.048		0000	6881.983 s	Cr	0
6864.585		000	6882.784 s	Cr	1
6864.775		0000	6883.325 s	Cr	1
6865.206		0000	6883.635		0000
6865.704		0000	6884.076 s [3]	A (O)	10
6865.906		000	6884.656		00C0 N
6866.243		0000	6885.221	A?	0000
6866.604		000 N	6885.598	A?	0000
6867.037		0000 N	6886.000 s	A (O)	11
6867.457 s [1]	A (O)	6d?	6886.446	A?	00C0 N
6867.631	A	1	6886.990 s	A (O)	12
6867.800 s	A (O)	5	6887.242		000
6868.092 s	A	0 Nd?	6887.444		000
6868.336 s	A (O)	6	6887.705	A	000 Nd?
6868.478 s	A (O)	6	6887.969	A	000
6868.645 s	A	1	6888.250	A	000
6868.795 s	A	3	6888.670		0000
6869.142 s	A (O)	7	6888.830		0000
6869.353 s	A (O)	6	6889.192 s	A (O)	13
6869.850	A?	00	6889.490		000
6870.116 s	A (O)	7 d	6889.827		0000Nd?
6870.249 s [2]	A (O)	7	6890.151 s	A (O)	14
6870.853	A?	000 N	6890.460		000
6871.180 s	A(O)	8	6891.000	A	000
6871.532 s	A (O)	10	6891.180	A	000
6872.105	A ?	000	6891.617		0000 N
6872.486 s	A (O)	11	6891.843	A	000
6873.080 s	A (O)	12	6891.970	A	0000
6873.630	A?	0000	6892.618 s	A (O)	14
6874.037 s	A (O)	12	6893.099		000
6874.899 s	A (O)	13	6893.560 s	A (O)	15

[1] First line in the head of the B group, due to atmospheric oxygen. [2] Principal line in the head of the B group. [3] First line in the tail of the B group.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
6894.068		0000 N	6913.810		0000
6894.320		0000 N	6913.945		000
6894.660	A	000	6914.158		0000
6895.200	A?	000 N	6914.337 s	A (O)	11
6895.630		000 N	6914.668		0000
6895.737	A?	0000	6914.823 s	Ni	4
6896.289s	A (O)	14	6915.075		0000 N
6896.660		0000 N	6915.270		0000 N
6896.882		0000	6915.775	A	000 N
6897.208 s	A (O)	15	6916.136	A	000 N
6897.673		0000 N	6916.325		0000 N
6897.837		0000 N	6916.743	A	0000 N
6898.160	A?	000 N	6916.948 s		2
6898.556		00	6917.235		000 N
6898.766		0000 N	6917.710	A	000 Nd?
6899.130		0000 N	6918.015		0000
6899.710		0000	6918.370 s	A (O)	9
6900.199 s	A (O)	14	6918.655	A?	000
6900.734		000 N	6918.860		0000
6901.117 s	A (O)	15	6919.250 s	A (O)	9
6901.527		0000	6919.556	A	000
6901.810		000 N	6920.430		00
6902.065		0000	6920.650		0000
6902.443		0000	6921.135	A?	0000
6902.901		0000	6921.615	A?	000
6903.120		00	6921.834	A?	0000
6904.362 s	A (O)	14	6922.238	A?	000
6904.785		000	6922.548	A?	0000
6905.083		0000	6922.735	A	000
6905.271 s	A (O)	14	6922.912		0000
6905.540		000	6923.553 s	A (O)	9
6905.915		0000	6924.080	Cr?	0000 N
6906.295	A	000	6924.427 s	A (O)	9
6906.560		000 Nd?	6924.713	A	000 N
6907.282	A	000	6925.134	Cr?	0000 N
6907.920	A	000	6925.543		1
6908.360		0000	6925.752		0000
6908.783 s	A (O)	13	6926.170		0000
6908.251		0000 N	6926.363		0
6909.676 s	A (O)	13	6926.660		0000
6910.270		0000 N	6926.850		000
6910.510	A?	000 N	6927.020	A	00
6910.994		0000	6927.520	A?	000
6911.310	A	000 N	6927.948		0000
6911.790	A_1	00 N	6928.500		000
6912.173	A	000 N	6928.796		0000
6912.690		0000 N	6928.977 s	A (O)	4
6913.038	A	000 N	6929.227	A?	0000
6913.284	Ti?	0000	6929.375	A	000
6913.448 s	A (O)	11	6929.560	A (wv)	00

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
6929.840 s	A (O)	4	6943.379		0000
6930.075	A	00	6943.689		0000
6930.185	A	000	6943.904		0000
6930.600		0000 N	6944.060	A (wv)	3
6930.890		00 N	6944.510		0000
6931.355		0000	6944.861		0000
6931.575	A	00 N	6945.135		0000
6932.012	A	00	6945.477		4
6932.298		0000	6945.745		0000 N
6932.445	A	00	6946.160		000 N
6932.765		0000	6946.638		0000
6933.024		0000	6946.860	A (O)	0
6933.305		0 N	6947.191		0000 N
6933.469		0000	6947.406		0000
6933.715		000	6047.702	A (O)	0
6933.887		2	6947.782 s	A (wv)	5
6934.075	A (wv)	2	6947.863	A wv	00
6934.325		0000	6948.146		0000 N
6934.468		0000	6949.240	A (wv)	1
6934.670 s	A (O)	2	6949.310	A (wv)	1
6934.870		000	6950.188		0000 N
6935.153		0000	6951.010	A (wv)	1
6935.355	A?	000	6951.518		1
6935.530 s	A (O)	2	6951.900	A?	000
6935.704	A?	0000	6952.593	A	000 N
6936.075	A	000 N	6953.337	-,A (O)	00 N
6936.290		0000	6953.828 } s	A (wv)	1
6936.755		000 N	6954.020 }	A (wv)	00
6937.122		0000	6954.147	A (O)	000
6937.420		000 N	6954.718	A ?	0000 N
6937.957	A (wv)	2 N	6955.307		00
6938.195		000	6955.507	A	0000
6938.520	A (wv)	1 N	6955.915	A (wv)	000 N
6938.727		000	6956.660 } s	A (wv)	4
6939.050		000	6956.746 }	A (wv)	1
6939.460		0000	6957.675	A	000
6939.875	A (wv)	2	6957.985		0000
6940.030		0000	6958.753	A?	0000
6940.270		0000	6959.704 s	A (wv)	3
6940.436	A (wv)	2	6960.105	A (O)	000 N
6940.625	A (O)	1	6960.590		00
6940.861		0000 N	6960.880	A (O)	0000
6941.023		0000	6961.136		0000
6941.260	A (wv)	000 N	6961.515 s	A (wv)	4
6941.475	A (O), A (wv)	1	6962.075		0000 N
6941.979		0000 N	6962.213		0000 N
6942.402	A (wv)	2	6963.100		000 N
6942.630	A (wv)	1	6963.900	A	000 N
6942.746		0000	6964.447		0000
6943.083		000	6964.812	A (wv)	1

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
6965.320	A	000 N	6992.065	A	000 N
6965.716		00	6992.571		0000
6966.158		000	6993.145	A	00 N
6967.054		0000	6993.776	A (wv)	2
6968.837		0000	6994.360	A (wv)	1
6969.302		0000	6994.635		0000
6970.763	A	00	6994.880	A	00
6971.135	A (wv)	0	6995.260		0000
6971.400		0000	6996.930		0000
6971.772		000	6997.420	A?	0000
6972.205		00	6998.070	A?	0000
6973.132		0000	6998.283	A	00
6973.743	A	0000 N	6998.500		0000 N
6974.600		0000	6998.978 } s	A (wv)	0
6974.996	A?	000 N	6999.223 }	A (wv)	2
6975.706		0	6999.488	A	0000
6975.976		0000	6999.823	A	0000
6976.535		000 N	7000.155 s		1
6976.783		1	7000.411		0000
6977.198		00	7000.555		0000
6977.715	A (wv)	3	7000.880		00
6978.138		0000	7001.125	A	000
6978.310		0000	7001.475		0000
6978.670 s		1 N	7001.810		00
6979.120		2	7002.385	A	00 N
6979.420	A	000 N	7002.870		0000 N
6979.610		0000	7003.837		1
6980.060		1	7004.240		0000 N
6980.620	A?	0000 N	7004.575	A (wv)	0 N
6981.196		000	7004.995	A (wv)	2
6981.722	A (wv)	1	7005.365	A (wv)	0 N
6981.860	A?	000	7005.608	A	0000
6982.501		000 N	7005.850	A	000
6982.780		0000 N	7006.157 s		1
6983.810		000 N	7006.420	A	000 Nd?
6984.380		0000 N	7006.915	A	000
6984.870		0000	7007.140		0000 N
6985.220	A (wv)	0 N	7007.385	A	0000 N
6985.776		0000	7007.970	A	000 N
6986.080	A	000	7008.225		0
6986.833 s	A (wv)	3 N	7008.515	A	00 N
6988.125	A (wv)	0 N	7008.920	A?	0000
6988.536		0000 N	7009.485	A	000 N
6988.805		0	7010.135	A (wv)	0 N
6989.075		0000	7010.618		000 N
6989.237 s	A (wv)	3	7010.920	A	0000 N
6989.825		000 N	7011.230	A	000 N
6990.230	A?	0000	7011.590 s	A (wv)	2
6990.632	A (wv)	1	7012.130		0000
6991.295	A	000	7012.490	A	0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
7012.880		0 N	7037.800	A	1
7013.550		000 N	7038.061		0000
7014.080		000	7038.202		0000
7014.810		0000 N	7038.500 s		1
7015.260		000	7039.040		0
7015.560	A	000 N	7039.560	A	0 N
7015.800		0000 N	7040.053 s		1 N
7016.176		0000	7040.861		0000
7016.330 s	-,A (wv)	1	7042.025		00 N
7016.675 s	-,A (wv)	3	7042.745		0000
7017.020		000 Nd	7044.265		0000 N
7017.575	-,A	00 Nd	7044.777		000
7017.935		0	7044.952		00
7018.250		0000	7045.313		000
7019.043	A	000	7045.517		0000
7019.620	A	0	7046.056		0000
7020.445	A?	0000	7047.133		00
7020.900	A	000	7047.631		000
7021.100	A	000	7048.291		0000
7021.790	A	0000	7049.273		0000
7022.302		0000	7050.783	A?	000
7022.662		000	7051.115		0
7022.810	A	000	7052.030	A?	0000 N
7023.230 s		2	7052.665	A?	000 N
7023.550		0000	7053.070		1
7023.770 s	A (wv)	2	7053.191	A?	0
7023.983		0000 N	7053.755		0000 N
7924.340		0	7054.280		000 N
7024.660		0000	7054.970	A	00 N
7024.913 } s		1	7056.210		00 N
7025.140 }	A	0	7056.750		0000
7026.660	A	00	7057.260	A	0 N
7026.890		0000	7057.590		0000
7027.213 s	-,A (wv)	0	7057.820		0000
7027.740 s	-,A (wv)	2	7058.186		0000
7028.115	A	0	7058.490	A?	000
7028.466		0000	7059.825		0000 N
7028.860		0000 N	7060.314		0000
7029.260	A	0	7060.725		1 N
7029.390		00	7061.780	A	00 N
7029.975	A	0000 N	7062.265		0000
7030.295		0	7062.750		0000
7030.657		0000	7063.255		000 N
7031.215	A	00 N	7063.770	A?	0 N
7032.585		1	7064.400		0000
7034.360	A?	0000 N	7064.917	A?	000
7034.670	A	0000 N	7065.496		0000
7035.170 s		2 N	7065.920		1
7036.129		0000	7066.495		000 Nd?
7037.465	A	0	7067.210		00 N

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
7067.742		000 N	7097.395		000 N
7068.265		000 Nd?	7097.940		0000
7068.685		2	7099.219		0000 N
7068.870		000 N	7099.812		0000 N
7069.350		0000 N	7100.415		000 N
7069.820		0000	7100.960		0000 N
7070.934		0000	7102.222		0000 N
7072.130		0 N	7102.560		000 N
7072.720		000	7103.430		000
7073.070		0000	7105.422		0000
7073.890		000 N	7106.434	A?	000 Nd?
7074.757		0000 N	7107.300		0000 N
7075.188		0000	7107.740		0
7075.875		0000	7108.187		0000 N
7077.087		0000	7108.387		0000 N
7078.109		000 N	7109.310	A	000 Nd?
7078.540	A?	00 N	7110.700		0000 N
7079.130		000 N	7111.180		1
7079.685		0000	7111.730	A	000 N
7079.870		000 N	7112.199	A	0000
7081.210		000	7112.450		0
7082.445		0000 N	7113.010		0000 N
7082.755		0000 N	7113.455	A?	00 N
7083.104		0000 N	7113.700		0000
7083.680		00 N	7113.870		0000
7083.993		000 N	7114.313	A?	0000
7084.235		000 N	7114.447	A?	0000
7084.531		0000	7114.860		000
7084.920		0000 N	7115.444	A?	000
7085.265		2 N	7115.591	A?	0000
7085.810		0000 N	7116.670		0000 N
7086.590		0000	7117.240		000 Nd?
7087.008		00	7117.549		000
7087.550		0000 N	7117.948		0000 N
7088.099		0000 N	7118.390	A?	000
7088.430	A?	00 N	7118.554	A	1
7090.000		0000 N	7119.254		0000
7090.660		2	7119.955		000 N
7091.430		0000	7120.320		000 N
7091.640		000	7121.965		0000 N
7092.220		000 N	7122.484		4
7093.120		0000	7123.000	A?	0000
7093.395		000	7125.269	A?	0000
7094.009		0000	7126.414	A?	0000
7094.305		0000	7127.087		0000 N
7094.615		0000	7127.845		0 N
7095.295		0000 N	7128.390	A?	000 N
7095.690		0	7128.810		0000 N
7096.140		000	7129.410	A?	0000 N
7096.660		0000	7130.140		0000 N

Wave-length	Substance	Intensity and Character	Wave length	Substance	Intensity and Character
7131.204		3	7164.725[1]	-, A	2
7131.650		000 N	7165.018		000 N
7132.043	A?	0000	7165.396		0000 N
7133.263		1	7165.845	A,-	1 N
7133.660		000 N	7166.355	A	000 N
7134.423	A	00 N	7166.553	A	0000
7136.120		000 N	7166.931		0000
7137.720	A	1 N	7167.305	A	000 Nd?
7138.209	A?	0000 N	7167.645	A	00
7139.215		000	7168.170	-,A	4 N
7139.973		0000 N	7168.465	A	0000
7140.568	A	000 N	7168.748	A	0000
7141.360	A	0000	7169.017	A	0000
7141.930		0000 N	7169.355	A?	00
7142.451	A	0000 N	7170.102	A?	0000
7142.800		0	7170.360	A	00
7143.257	A	1	7170.619	A?	0000
7143.660		0000	7170.833	-,A	1
7144.229		0000	7171.130	A	0000 N
7145.022	A	0000	7172.250	A	300 N
7145.615		1	7172.970	A,-	1
7147.939	A	2 N	7173.200		000 N
7148.435		3 N	7173.675	A,-	2
7148.793		0000	7174.040	A	0
7148.995		000 N	7174.440	A	0
7149.574		0000	7174.930		0000 N
7150.100	A?	0000	7175.580	A?	0000Nd?
7150.450	A?	0000 N	7176.225	A,-	1
7150.947	A	1	7176.430	A	1
7151.442	A	1	7176.719		0000
7151.765		00	7177.170	A	0
7152.375		0000	7177.390	A	0
7153.627	A?	0000	7177.640	A,-	2
7154.030		0000	7177.915	A	2 N
7155.014		0000 N	7178.690	A	00 N
7155.945		0 N	7179.060		0000
7156.700	A	1 N	7179.570	A	000
7157.438		0000	7179.910		0000 N
7158.084	A?	0000	7180.300	A	000
7158.790		000 N	7181.500	A	0
7159.045	A	0 N	7181.790	-,A	2
7159.590	A	00 N	7182.045	A	1
7160.602		0000 N	7182.260	A?	00
7161.154		0000 N	7182.658	A	0000
7161.746		0000 N	7183.089	A	0000
7162.352	A	00 N	7184.650	A	3
7162.630		000 N	7184.785		4
7163.012		0000	7185.205		000 N
7163.469		0000	7185.580		0000 N
7164.125	A?	000 N	7185.870		0000 N

[1] This is the beginning of the "a" group; most of the atmospheric lines are produced by water vapor, but as the identification is somewhat uncertain in many cases, and as some of the lines may be due to other atmospheric gases, they have simply been marked A.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
7186.405	A	4	7209.780	A,-	3
7186.655	A	5	7210.679	A	000 N
7187.280	A	2	7211.473	A	1
7187.645	-,A	5 N	7212.308	A	000 N
7188.286		0000 N	7212.740	A	00
7188.875		0000 N	7214.166	A	000
7189.242	A	0000	7215.042	A,-	000 N d
7189.445	A	00	7215.782	A?	000 N
7189.740		0000	7216.482	A	000
7190.159		000	7216.791	A,-	2
7190.427		000	7216.927	A?	0000
7191.755	A,-	6 N	7217.479		0000 N
7192.150	A	2 N	7218.323	A	000 N
7192.745	A	1 N	7218.799		000 Nd
7193.039		0000	7219.337	A	0000 N
7193.475	A	000 N	7219.987		0
7193.835	A	3	7220.306	A	0000 N
7194.040	A	3	7221.088	A	0000 N
7194.655		0000	7221.492		0
7194.871		0000	7221.870	A?	0000
7195.290	-,A	2	7222.691		000 N
7195.827		0000	7223.216	A	00 N
7196.070	A	0 N	7223.930 s	A	3
7196.716	A?	0000 N	7224.414		0000
7197.300	A	0	7224.791		000 N
7197.515	A	1	7225.356		0000
7197.698	A	000	7226.522	-,A	000 N
7198.145	A	1 N	7227.781 s		3
7198.705	A	2	7228.468	A?	0000
7199.152		0000 N	7229.013	A?	000
7200.095		000	7229.424		0000
7200.378		0000	7232.520 s	A	1
7200.665	A	2	7233.170 s	A,-	3
7200.800	A,-	4	7234.688	A	0
7201.460	-,A	4	7235.011	A	2
7201.728	A	0	7235.658		000 N
7202.485		1 N	7236.142		000 N
7202.843		0000	7236.418	A	1
7202.138		0000	7236.695	A	00
7203.135	A	2	7238.216	A	0000 N
7204.577	A,-	5	7239.281	A	0000
7204.672		00	7239.765		0000
7205.022		0000	7240.149	A	1
7206.692	,A	6	7240.883 } s	A	3
7207.165		0000	7241.099 }	A	2
7207.415		00	7243.750 } s	A	1
7207.715		1	7244.004 }	A	2
7208.079		0000	7245.152		00
7208.511		0000	7245.959	A	2
7209.427		0000	7246.457		0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
7247.091		0000	7277.469	A	000
7247.494 s	A	1 N	7277.678		2 N
7248.047		0000 N	7278.385	A	0 N
7249.244	A	0 N	7278.762	A?	000
7249.581		0000	7280.042	A	00 N
7250.511	A	1 N	7280.890	A	00 Nd
7250.928		00 N	7281.913		0000 N
7252.032		000 N	7282.600	A	1 N
7252.355	A	0	7283.112		000 N
7252.664	A	2 N	7283.435	A	000
7253.137	A	00	7284.107		0000 N
7253.493	A	1	7285.158		00
7254.002	A	1	7285.576	A	000
7254.576		0000	7286.249		0000 N
7254.940		000	7286.828		0000 N
7255.586		0000	7287.673 s	A	2 N
7256.422		000	7288.073	A	0000 N
7257.392	A	000	7288.416		1
7257.674	A	00	7289.049		00
7258.226	A	1 N	7289.466		0 Nd?
7258.939		0000 N	7290.087	A	00 N
7259.357		0000 N	7290.686 s	-,A?	3 N
7259.895		0000 N	7291.366	A	0 Nd?
7260.462	A	000 Nd?	7291.757	A	00
7261.028	A	0	7292.025		0000 N
7261.310		0000	7292.409	-,A	0 N
7261.808	A?	00 N	7293.009	-,A	0 N
7262.260	A	1	7293.372	A	000 N
7262.576		0000	7293.655	A	00
7263.277	A	000	7294.166		0000 N
7263.640	A	0000	7294.651	A	00
7264.125		0000	7295.042	A	000
7264.676	A	00	7295.325	A	1
7264.892 s	-,A	2	7295.903	A	00 N
7265.431		0000 N	7296.536	A	00
7265.868 s	-,A	5	7299.917 } s	A	0 N
7266.441		0000 N	7300.226 }	A	1 N
7267.101		0000 N	7300.846		000 N
7268.865		0000 N	7301.169		0000
7269.566		0000 N	7301.599		0000
7270.065 } s	A	00 N	7301.801		0000
7270.414 }	A	000	7302.394	A	00
7273.255 s	A?,-	5 N	7302.906	A	000 N
7273.941		0000 N	7303.162	A	0000
7274.952		0000 N	7303.485		2
7275.675		2 N	7304.078		0000 N
7276.083	A	000 N	7304.468 s	-,A	3 N
7276.581	A	00	7305.195	A	0000 N
7276.810	A	00	7306.878		00
7277.146	A	00	7307.282		0000 N

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
7308.253		00 Nd?	7316.223	A	000 N
7309.047	A	1	7317.112	A	00 N
7309.788	A	2 N	7317.611	A	0 N
7310.474	A	00	7318.405	A	00
7311.403	-,A	0 Nd?	7319.015	-,A?	1
7312.279		0000	7321.030 s	A	1 Nd
7312.911	A	1	7324.249	A	1
7313.504	A	000 N	7326.462		0
7314.797	A,-	000	7327.750	A	1
7315.416		0000 N	7331.225 s		1 N
7315.834	A	0			

Minor Contributions and Notes.

THE EFFECT OF A TOTAL ECLIPSE OF THE SUN ON THE VISIBILITY OF THE SOLAR PROMINENCES.

In his recent valuable report on the total solar eclipse of April 16, 1893,[1] Professor J. M. Schaeberle sums up his conclusions with regard to the prominences in the following words: "All visible matter exterior to the Sun's surface is apparently in rapid motion, the path described corresponding to one of the conic sections. The so-called stationary prominences are probably stationary as to the general form only, the matter — which remains visible so long as the density is sufficiently great — in the same being in rapid motion. I have carefully compared the eclipse photographs taken with the 40-foot telescope on April 16, 1893, with the best spectroscopic observations accessible (both visual and photographic), taken of the uneclipsed Sun on the same day, and the result briefly stated is that while the coarser features of the Sun's surroundings are shown in spectroscopic observations of the uneclipsed Sun, *the finer and essential details are wanting.*" On another page (93) Professor Schaeberle concludes, from a comparison of his eclipse photographs with the visual and photographic results obtained by Herr Fényi and myself on the same day at Kalocsa and Chicago, that the reason this structure of the prominences has not been more generally recognized is "the want of sufficient scale and definition." As Professor Schaeberle's photographs of the corona and prominences are undoubtedly superior to any obtained at previous eclipses, he is in possession of the very best of data for a study of the question. The importance of the subject has, however, seemed to me sufficient to warrant a further brief reference to my own observations, in connection with a review of certain other investigations made at various total eclipses since 1870.

The extensive series of observations made by Professor P. Tacchini at the eclipses of 1870, 1882, 1883 and 1886 are of great importance in connection with the work of Professor Schaeberle, and as they are not referred to by him, and seem to have been overlooked in many dis-

[1] *Contributions from the Lick Observatory, No. 4*, p. 125.

PLATE XXV.

PROMINENCE PHOTOGRAPHED BY PROFESSOR J. M. SCHAEBERLE DURING THE TOTAL ECLIPSE OF 1893, APRIL 16.

cussions of the nature of prominences, I have brought together below some of the most remarkable results.[1]

The eclipse of 1870 was observed by an Italian party stationed at Terranova, Sicily. During the total phase drawings of the prominences were made by Messrs. Legnazzi and Müller, which agree closely as to their general form. These were compared by Professor Tacchini with drawings of the prominences made with the spectroscope immediately after totality, with the following result: "Da questo confronto ci pare di potere arrivare alla seguente conclusione, che cioè durante gli eclissi totali di sole le protuberanze, che allo spettroscopio si mostrano tutte composte di parti ben distinte e frastagliate, si presentano invece sotto forma di masse compatte o nebulose, la cui forma si addatta però all'ossatura o scheletro che noi vediamo allo spettroscopio; di modo che se le osservazioni spettroscopiche sono fatte prima dell'eclisse, non sarà difficile prevedere quale forma presenteranno le protuberanze durante l'eclisse totale. Esisterebbe dunque un involucro comune, una atmosfera avvolgente le parti, che noi vediamo in pieno sole, la quale atmosfera non riuscirebbe a noi visibile, per debolezza di lume, che nelle sole circostanze di eclissi totali."[2]

At the Egyptian eclipse in 1882, Professor Tacchini devoted special attention to a repetition of these observations. On the three days preceding the eclipse drawings of the chromosphere and prominences were made in accordance with the system so long pursued by the same observer at Palermo and Rome, and just before totality another drawing was made with great care, and the height and width of base of the four principal prominences measured with a micrometer. During totality the same prominences were observed with the naked eye, and their dimensions determined with reference to the lunar diameter. The results are given in the following table, together with the heights of the same prominences measured by Professor Riccò at Palermo on the day of the eclipse:

Latitude of the Prominence	Height observed with the spectroscope		Height observed during the eclipse	Difference (Tacchini)	Base observed with the spectroscope	Base observed during the eclipse	Difference
	Tacchini Sohag	Riccò Palermo					
+18°	72″	75″	180″	108″	100″	180″	80″
+29	60	62	162	102	50	108	58
−15	48	47	180	132	100	231	131
−22	36	63	180	144	82	231	149

[1] Taken for the most part from Professor Tacchini's work, *Eclissi totali di Sole del 1870, 1882, 1883, 1886 e 1887* (Roma: Tipografia Eredi Botta, 1888).

[2] *Loc. cit.*, p. 234.

In the hope of obtaining independent evidence regarding the dimensions of the prominences during totality, I have examined an excellent positive on glass made from one of the photographs taken at this eclipse. Unfortunately the lower parts of the prominences are so covered by the Moon's disk as to render measurement of the full height and width impossible, the time which had elapsed since the beginning of totality not being recorded on the photograph employed. The dimensions of the prominences seem, however, to exceed those found by Professor Tacchini before the eclipse. A most interesting fact is the presence on the photograph of a large number of small prominences not recorded in the spectroscopic observations of the chromosphere. It is well to bear in mind that these observations were made in the *Hα* line, and that the photographs taken during totality with the prismatic camera showed differences in the relative intensities of the prominence lines.[1] The reliability of Professor Tacchini's observations is further indicated by the appearance of the prominences during totality: "Le quattro protuberanze erano tinte in roseo chiaro, e molto più lucenti ai bordi e tanto che sembravano contornate da un filetto lucido bianco."[2] In view of Professor Tacchini's long experience as an observer of prominences, it may safely be said that these results should be considered to confirm those obtained at Terranova, and may be accepted as establishing an important difference between the spectroscopic and eclipse images of prominences.

In 1883 Professor Tacchini observed the eclipse at Caroline Island, and not only confirmed his earlier work, but discovered a new and remarkable variety of prominence: "Una cosa, che mi sorprese e che aveva un aspetto singolare e per me nuovo, erano dei getti o protuberanze bianche, la cui altezza non doveva essere minore di ⅓ del raggio lunare. Questi oggetti sembravano proprio come di argento filogranato, di una struttura cioè ed apparenza del tutto consimile a quella da me indicata per l'oggetto veduto al 1882 e che si definì per una cometa."[3] These "white" prominences were not visible in the spectroscope immediately after the eclipse. During totality the chromosphere was found to be much higher than in full sunlight observations.

At the Grenada eclipse in 1886 Professor Tacchini's discovery of white prominences was amply confirmed by the appearance during

[1] SCHUSTER and ABNEY, *Proc. R. Soc.*, **35**, 153, 1883.

[2] *Eclissi totali*, p. 16.

[3] *Ibid*, p. 58.

totality of a prominence from 10′ to 12′ high, independently seen by three observers and recorded on all the best photographs. To Professor Tacchini it appeared of a silver white color in its upper part, with a slight tinge of rose below.[1] Mr. Maunder described it as "of the intensest silver whiteness,"[2] while Professor Turner considered it to have a rosy tint throughout totality.[3] A searching spectroscopic examination of the chromosphere made immediately after totality failed to show any indication of this remarkable object, which was also invisible with the spectroscope at Rome and Palermo. Professor W. H. Pickering photographed the spectrum of this prominence, and found H and K without the hydrogen lines.[4] Captain Darwin found from an examination of the photographs taken with a prismatic camera that $H\beta$, $H\gamma$, $H\delta$, $H\zeta$ and f were probably also present, though they were extremely faint in comparison with the brilliant H and K lines.[5]

Professor Tacchini found that of the nine prominences seen during totality but four were visible in full sunlight, apparently much reduced in both height and width of base. "Insistiamo intanto nel dire, che inquanto a cromosfera, ciò che vedesi tutto attorno al sole durante un'eclisse totale, non è paragonabile colla cromosfera veduta in pieno sole, perchè durante un'eclisse totale si vede uno strato roseo sfumato fino al bianco, al disopra del quale s'innalzano le grandi protuberanze, mentre i fiocchi lucenti e le piccole protuberanze che noi vediamo allo spettroscopio si confondono con quell' involucro stupendo, che deve venire formato dalla nebbia lucida più elevata ed involgente le piccole fiammelle, di cui vediamo costituita la cromosfera in pieno sole."[6]

These various observations have led Professor Tacchini to the following classification of solar prominences:

"1. Protuberanze visibili in pieno sole e durante l'eclisse totale, ma ben più alte, larghe e compatte, senza cioè il frastagliamento che si osserva quasi sempre nello spettroscopio a sole non eclissato.

2. Protuberanze visibili in pieno sole e durante la totalità, con poco differenza nella forma.

[1] *Ibid*, p. 187.

[2] *Phil. Trans.*, **180**, 345, 1889.

[3] *Phil. Trans.*, **180**, 392, 1889.

[4] *Annals of Harvard College Observatory*, **18**, 99.

[5] *Phil. Trans.*, **180**, 320, 1889.

[6] *Loc. cit.*, p. 197.

3. Protuberanze visibili durante l'eclisse totale e non visibili in pieno sole.

4. Cromosfera solare sempre più compatta ed alta durante un'eclisse totale, in confronto di quanto ci mostra lo spettroscopio a sole libero."[1]

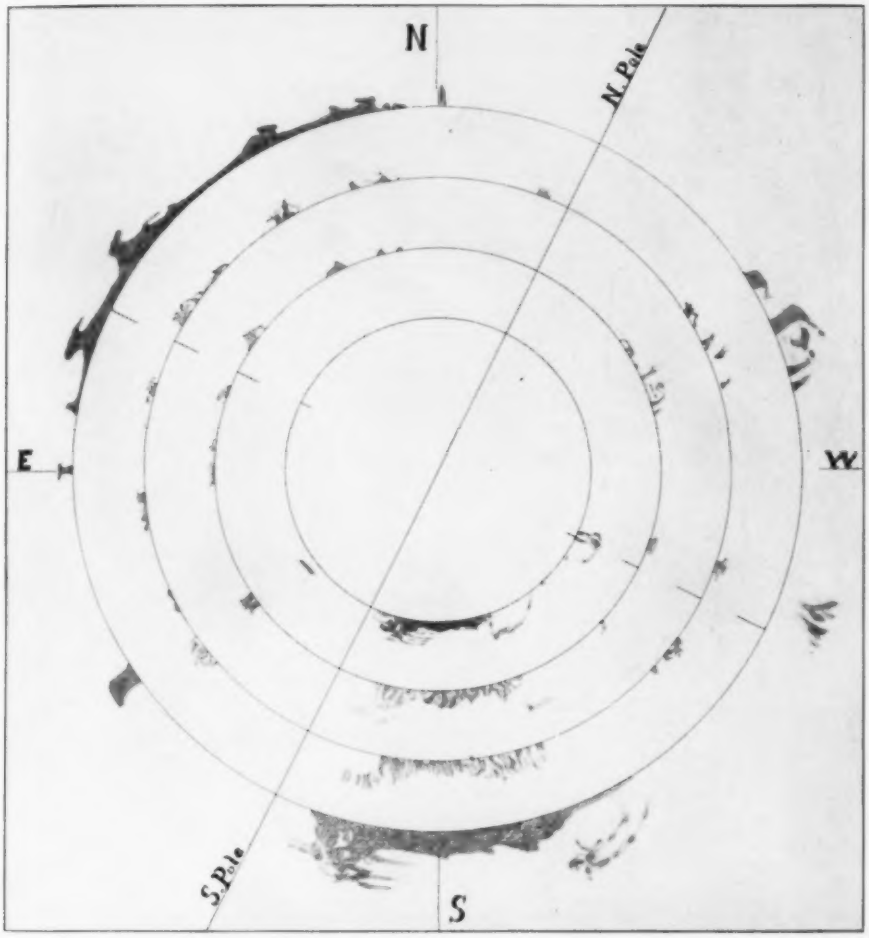
Let us now consider the observations made at the eclipse of 1893, April 16. Plate XXVI., which is reproduced from a drawing made by my assistant, Mr. Ellerman, brings together the visual and photographic results obtained by four observers. Fig. 1 (the outer circle) represents the prominences photographed by Professor Schaeberle at Mina Bronces, Chile, with a photoheliograph of 40 feet focal length. The drawing was made from a series of beautiful positives on glass from the original negatives, presented by the Lick Observatory to the Yerkes Observatory. While it fails to show all that could be seen on the original negatives, it is perhaps sufficiently complete for our present purpose. On account of the overlying image of the Moon, the forms of the lower parts of some of the prominences are very uncertain. For this reason no attempt was made to indicate the base of the prominence at P. A. 294°. Fig. 2 (from a plate in *A. N.* 3166) represents the prominences as drawn by Herr Fényi at Kalocsa, Hungary, at the time of totality in Chile. The observations were made in the *Hα* line with a Hilger 6-prism automatic spectroscope attached to a 7-inch refractor. All of the prominences (excepting one at P. A. 30°, which showed some motion in the line of sight) were of the quiescent type, and changed but very little in form or position during the day. The weather at Kalocsa was particularly favorable.[2] Fig. 3 was drawn from two negatives of the prominences made in the K line with the spectroheliograph attached to the 12-inch telescope of the Kenwood Observatory.[3] It was cloudy here at the time of totality in Chile, and no photographs could be made until about two hours later, when the thick haze which still covered the Sun made satisfactory observations impossible. Considering the circumstances in which they were made, it is not surprising that the photographs are decidedly inferior to those ordinarily obtained here. Fig. 4 shows the two large prominences at P. A. 180° and P. A. 294° as photographed by Mr. A. Fowler during totality at Fundium, Africa. The instrument used was a prismatic camera of 6 inches aperture with a prism of 45° angle. The drawing was copied from the K image on a beautiful glass positive, one of a series of photographs of this

[1] *Loc. cit.*, p. 236.

[2] *A. N.* 3166, p. 365, 1893.

[3] *A. and A.* 12, 450, 1893.

PLATE XXVI.



PROMINENCES OF 1893, APRIL 16:

(1) Photographed during total eclipse by Professor J. M. Schaeberle at Mina Bronces, Chile (outer circle).

(2) Observed visually in full sunlight by Herr J. Fényi at Kalocsa, Hungary.

(3) Photographed in full sunlight by Professor George E. Hale at Chicago, U. S. A.

(4) Photographed during total eclipse by Mr. A. Fowler at Fundium, Africa (many prominences not shown in the drawing).

eclipse which I owe to the kindness of Mr. Fowler. As some of the prominences are hidden on this positive by the Moon's disk, it has been thought sufficient to reproduce only those shown in Fig. 4.

The following table gives the approximate position angles and heights of the prominences recorded by Professor Schaeberle, Herr Fényi and myself. The lack of agreement of the position angles in many cases seems to be due in part to the different methods of designating the prominences adopted by the several observers.

Schaeberle		Fényi		Hale	
P. A.	Height	P. A.	Height	P. A.	Height
4°	0′.8	.....	.....	.....	.....
7°	0′.8	.....	.....	.....	.....
9°	0′.8	10°	(small)	9° to 10°.5	0′.3
11°	1′.0	.....	.....	.....	.....
17°	1′.0	.....	.....	14° to 16°	0′.5
18° to 27°	0′.5 to 0′.2	.....	.....	24° to 29°	0′.7
30° to 58°	1′.0 at 30° 1′.3 at 58°	28°30′ to 33° 24°; 53° 16′ to 60°6′	44″ 51″	.....	.....
59° to 69°	0′.7	.....	.....	.....	.....
69° to 77°	1′.0	73°34′ to 75°48′	33″	68° to 74°	0′.7
77° to 83°	(seven small prominences)	.....	.....	.....	.....
87° to 96°	1′.1	94° to 101°	(small)	86° to 99°	0′.4
125° to 130°	1′.5	124°32′ to 130°50′	54″	124° to 127°	1′.0
165° to 215°	3′.2 at 168° 1′.0 at 192° 1′.5 at 197° 3′.8 at 202°	169°30′ to 201°4′	128″ at 168° 301″ at 201°4′	165° to 210°	2′.7 at 168° 2′.5 at 205°
.....	.....	226°	(small)	.....	.....
.....	.....	229°22′ to 233°48′	34″	226° to 228°	0′.7
250°	3′.0	251°	(small)	248° to 252°	0′.5
284°	1′.0	.....	.....	284°.5	0′.7
286° to 289°	1′.6	286°30′ to 287°8′	41″	286° to 287°	1′.2
289° to 291°.5	1′.8	292°	59″	289° 291°.5	0′.3 0′.3
289° to 294°	2′.8	.....	.....	.....	.....
294°	2′.2	294°26′ to 295°24′	54″	293°.5 to 295°	1′.4
300° to 302°	0′.8	303° to 304°	29″	300° to 306°	0′.5
.....	.....	339°	(small)	.....	.....
359°	1′.0	.....	.....	.....	.....

In comparing together these results the following summary of data relating to them will be of service:

SCHAEBERLE.—Eclipsed Sun. Clear sky. Large image. Superposition on photographic plate of images due to hydrogen, calcium and other substances, some of them necessarily not in perfect focus. Plate sensitive only in more refrangible part of spectrum: red, yellow and green images consequently lost or greatly underexposed. Base of many prominences covered by Moon.

FÉNYI.—Full sunlight. Clear sky. Small image, magnified by eyepiece of spectroscope. *Hα* line used, hence the prominence forms are those given by the red hydrogen line, which produced no effect upon the plates of the other observers. Necessary imperfections of hasty drawings, affected by insensitiveness of observer's eye to small contrasts. Time: about that of totality at Mina Bronces.

HALE.—Full sunlight. Very white sky. Small image, photographed by spectroheliograph without enlargement. K line used, giving distribution of calcium in prominences. Spectroheliograph of old type, in which image is distorted, making measurement of heights and position angles somewhat uncertain; motion of slits unsatisfactory, so that K line did not remain on the second slit during the entire time of one of the exposures. Time: about two hours after totality at Mina Bronces.

FOWLER.—Eclipsed Sun. Sky slightly hazy. Small image, photographed at focus of prismatic camera. Chromosphere and prominence images corresponding to a large number of lines shown on photographs, but only a portion of that corresponding to K reproduced here. Time: about two hours after totality at Mina Bronces.

A comparison of the hydrogen and other images with the calcium (K) image on Mr. Fowler's plates shows that the latter is the largest and brightest in the case of all the prominences. This was also found to be true at the eclipse of 1882, and might have been predicted from our knowledge of the relative length and brightness of the lines in the spectrum of the prominences. In Mr. Fowler's photographs the upper part of the prominence at P.A. 210° is shown in the *Hζ* line, though its images in the less refrangible hydrogen lines seem to have been hardly bright enough to affect the plate. It is faintly shown on my own plates, but was not seen by Herr Fényi in the *Hα* line. Quite apart from the question of brightness, however, it has been found at the Kenwood Observatory that the forms of prominences in the hydrogen and cal-

cium lines are in some cases distinctly different. Hence Herr Fényi's results should differ to a certain extent from the others, and, in general, the prominence forms observed visually should be somewhat smaller than the calcium images photographed with the spectroheliograph, or the composite forms photographed during a total eclipse. This failure of the ordinary visual method to render the true prominence forms visible in their full extent in sunlight must be regarded as having already been established by Professor Tacchini.

It is clear that on account of the greater size and brightness of the K image, photographs taken with the spectroheliograph should resemble eclipse photographs more closely than $H\alpha$ images do. It remains to be determined in what degree the results obtained with this instrument fall short of those obtained during total eclipses. Had the sky been clear in Chicago at the time of the eclipse it might have been possible to give a definite answer to this question. The fact that the prominences photographed by Professor Schaeberle considerably exceed in height those shown on my negatives is doubtless partly due to the difference in the atmospheric conditions and in the size of the image photographed. It is probable, however, that with apparatus such as that used by Professor Schaeberle during this eclipse, his conclusion is justified that faint details can be photographed which cannot be observed either visually or photographically in full sunlight. But before this can be considered definitely established it will be necessary to compare with eclipse results photographs taken simultaneously with a telescope of equal focal length and a spectroheliograph of the most approved type, under good atmospheric conditions.

In a paper published in 1891, I showed that the photographic method of recording the forms of prominences in the H and K lines, which was then giving its first results, would in all probability render possible the study of the "white" prominences in full sunlight. After pointing out the many advantages to be expected from the use of these lines in photographic observations of the prominences, I cited the fact that H and K, without the less refrangible hydrogen lines, were present in the spectrum of the great "white" prominence of the 1886 eclipse, in support of the conclusion that such prominences should be shown on spectroheliograms.[1] Since that time I have devoted some attention to a comparison of visual ($H\alpha$) and photographic (K) observations, but

[1] "Photography and the Invisible Solar Prominences," *Sidereal Messenger*, 10, 262, 1891.

I have not had an opportunity to investigate the matter thoroughly. I now wish to suggest that the prominence at P.A. 210°, which was photographed in South America, Africa and Chicago, but was not seen at Kalocsa in the *Hα* line, may have been an object of this class. I have found from an examination of Mr. Fowler's objective prism plates that, although the H and K lines were bright in this prominence, the hydrogen lines were so feeble as to make only the slightest impression on the plate. In some of the other prominences the hydrogen lines were nearly as strong as H and K, thus confirming the discovery of the different relative intensities of these lines made by Abney and Schuster at the Egyptian eclipse in 1883. Thus, in spite of the unfavorable atmospheric conditions which prevailed at Chicago, this prominence was photographed in the K line, while under the best of conditions it was invisible at Kalocsa in *Hα*.

Whether or not this prominence appeared white to the naked eye during totality, the published reports of this eclipse do not seem to say. It should be stated, however, that Mr. Fowler's plates apparently offer no evidence that this prominence was characterized by a continuous spectrum. But I venture to doubt whether a "white" prominence necessarily has a continuous spectrum. It is true that the striking object of this class observed at Grenada in 1886 had, according to Professor W. H. Pickering, "a brilliant continuous spectrum in the visible region,"[1] but I do not know that any confirmation of this result was obtained by the other observers. If it is true that H and K are the only intense bright lines in the spectra of the "white" prominences, it is perhaps unnecessary to seek further in order to discover the cause of the "white" color of these objects. Light of this wave-length, when observed in the spectrum of the electric arc, all other light being excluded from the eye, is of a distinctly violet color. Even the carbon flutings beginning at λ 3890 appear violet to the eye. But when the H and K lines are bright enough to be seen in the spectrum of a prominence, as is not infrequently the case, their violet color is so far diminished as to be hardly noticeable, and they appear distinctly white. I can account for this apparent difference only by supposing that the violet color is far less appreciable when the eye is exposed to the bright spectrum of the sky, as is the case when a prominence is under observation. The conditions existing during the total phase of a solar eclipse are very similar, for while observing the prominences the eye

[1] *Annals of Harvard College Observatory*, **18**, 99.

is exposed to the bright light of the corona. The light of the "white" prominences is also compared by the observer with the light of the corona and with the brilliant pink or red light of the ordinary prominences. As a result the violet color which must characterize all prominences in which the H and K lines predominate seems to escape attention. This may perhaps be due to a considerable admixture of white light radiated from or reflected by particles distributed throughout the mass of the prominence. I have occasionally found that eruptive prominences give a continuous spectrum,[1] but quiescent ones apparently do not, if we may judge from the fact that the spectrum of the sky is not materially brightened over such prominences. It is probably impossible to say at present whether the "white" prominences belong to the eruptive class, or to draw any *a priori* conclusions regarding the character of their spectra. It is to be hoped that special attention will be directed to this point at the coming eclipse.[2]

[1] *A. and A.* 11, 813, 1892.

[2] An examination of the literature of total solar eclipses will show that the depth of color of the prominences undoubtedly varies considerably. After due allowance has been made for personal equation, there seems good reason to believe that their color, which is ordinarily described as pink or rose, is sometimes deep ruby red and less frequently nearly white. Without attempting an exhaustive study of the literature with reference to this point, I have thought it worth while to append certain observations which are of interest in the present connection, though the scientific value of many of them is evidently doubtful.

In his *History of Astronomy* Grant quotes the following observations of the color of the prominences at the eclipse of 1842: Baily, red, tinged with lilac or purple; Biela, dark reddish color, approaching purple; Littrow, red, with a tinge of blue . . . . "their aspect, which was first white, changed to rose color and then to violet, and afterwards passed in a reverse order through the same tints. . . . The protuberances were visible *before they assumed a coloured hue*, and they continued to be visible after their colour was dissipated;" Valz, white, like the Sun. In 1868 Hennessy saw a prominence which differed in color from the others: "Its left edge was a bright blue, like a brilliant sapphire with light thrown upon it; next to that was the so-called rose-colour, and, at the right corner, a sparkling ruby tint" (*Proc. R. Soc.* 17, 86, 1868).

In his report on the eclipse of January 1, 1889 (*Reports on the Observations of the Total Eclipse of the Sun of January 1, 1889*, published by the Lick Observatory, p. 204) Dr. Swift quotes the following observations of prominence colors made at the eclipse of 1869: Alexander, white, later portions were tinted pale rose; Halstead, red, afterwards white; Hines, white, later brilliant rose; Browne, white, bordered with delicate rose; Zentmayer, white, tinged with blue; Moelling, white; Cutts, white; Schott, two prominences white, others delicate pink; Swift, bright red. In 1889 Kinne saw "a small, reddish purple Sun-flame near the north pole of the Sun"; Irish saw a

It has seemed to me worth while to point out, in the absence of more complete knowledge, that all of Professor Tacchini's classes of prominences can be accounted for with some degree of probability by the well-established fact of a considerable variation in the relative intensities of the hydrogen and calcium lines. His first class includes prominences which are visible in full sunlight and during a total eclipse, but in the latter case are much higher, broader and more compact, without the structure ordinarily observed with a spectroscope and an uneclipsed Sun. The photographs seem to show that the structure exists, though in a naked eye view during totality it might easily be overlooked. In attempting to explain the difference here noted let us remember (1) that such prominences were seen by Professor Tacchini to be bordered by a "white" fringe; (2) that H and K frequently seem to extend to a greater height than that attained by the *Hα* line in prominences, and that consequently the prominence image is often larger in K than in *Hα*; (3) that the spectroscopic images of many prominences do not end abruptly at a certain height above the limb, but disappear at a point where the ratio of their brightness to that of the spectrum of the sky does not exceed a certain quantity, which probably lies between $\frac{1}{3}\frac{1}{0}$ and $\frac{1}{5}\frac{1}{0}$. The reduction in the brightness of the sky during totality is probably great enough of itself to render visible faint parts of prominences that are invisible in *Hα* in full sunlight. The prominences must thus appear larger than they do in the spectroscope, and as the calcium extends further than the hydrogen, the pink image (which takes its color from the great visual intensity of the *Hα* light) must be bordered with violet, which, as I have already indicated, would not improbably appear white.

The second class comprises prominences visible in full sunlight and during totality, with little difference in form. These are probably bright prominences, which terminate abruptly or decrease very rapidly

cone-shaped prominence, having "a hue of ashes of roses"; Swift was much surprised to find the prominences "as white as burnished silver" (*Lick Observatory Report*, pp. 155, 193 and 203). Among the conclusions drawn by Secchi from his observations of the eclipse of 1860 is the following: "Les protubérances sont des amas de matière lumineuse ayant une grande vivacité et possédant une activité photogéniqué très-remarquable. Cette activité est si grande, que plusieurs des protubérances que nous voyons sur nos épreuves, et précisément la protubérance *E* (figured in *Le Soleil*), n' ont pu être observées directement, même avec de bons instruments: c'est peut-être parce qu'elles n' émettaient que des rayons chimiques et peu ou point de rayons lumineux." (*Le Soleil* 1, p. 385).

PLATE XXVII.

ERUPTIVE PROMINENCE PHOTOGRAPHED AT THE KENWOOD OBSERVATORY
1895, MARCH 24, 22^h 40^m CHICAGO M. T.

PLATE XXVIII.

ERUPTIVE PROMINENCE PHOTOGRAPHED AT THE KENWOOD OBSERVATORY 1895, MARCH 24, 22^h 58^m CHICAGO M. T.

in brightness at a certain distance from the limb, and give very bright hydrogen lines.

The third class comprises prominences visible during a total eclipse, but not visible with a spectroscope (using *Hα*) in full sunlight, *i. e.*, the "white" prominences. These seem to be prominences of moderate brightness, in which the hydrogen lines (particularly *Hα*) are very faint in comparison with H and K; they may perhaps also have a continuous spectrum. It is probable that they can be photographed in full sunlight with a spectroheliograph.

Finally, the chromosphere may have a "white" border and appear higher during totality, for the reasons given in the case of the first class of prominences.

It should be added that these suggestions are made only hypothetically, in the hope that they may be of some service in clearing up a long standing problem.[1] The rather full statement of Professor Tacchini's observations, which I have thought it well to give on account of the slight recognition this important work has received from many writers on solar phenomena, may perhaps serve to direct renewed attention to the prominences on the occasion of the coming eclipse.

As the prominences photographed at the Kenwood Observatory 1893, April 16, are not suitable for reproduction, I have thought it

[1] Former explanations of the "white" prominences include Lockyer's conclusion that they are descending masses of cooled vapor (*Eclissi totali*, p. 189) and the following from Proctor's *Old and New Astronomy*, p. 401: "This discovery (Tacchini's) seems only explicable by my theory that the ruddy, jet-like portion of the prominence owes its light, and therefore its heat, to the velocity of outrush with which ejected matter passes through the hydrogen and helium already outside the Sun, and not to the outrush of those gases themselves in an intensely heated condition. For outrushing gases brought from a region of great pressure to a region of very small pressure would expand rapidly and be quickly cooled, so that the outlines of the heated and luminous portion would be sharply defined, and they would be surrounded by a region not only cooler than the ejected matter, but even cooler than the surrounding atmosphere. On the other hand, ejected matter would travel outwards with diminishing velocity owing to the retarding action of solar gravity, while such portions as return after reaching a certain height would not only be scattered around somewhat widely, but would reach the Sun's surface with less velocity than they had at leaving it, because of the effects of frictional resistance. Hence, above and around the region of rapid outrush, intense heat, and brilliant light, there would be a region where the hydrogen and helium in the Sun's atmosphere would be heated by the rush of matter through it, and would therefore be luminous, but would be less heated than the region of outrush. This exactly corresponds with what Tacchini has discovered."

well to select from our collection three photographs (Plates XXIII., XXVII., and XXVIII.) for comparison with the largest prominence shown on the Mina Bronces negatives; this is the object at P. A. 210°, which may perhaps be a "white" prominence. Professor Schaeberle has been kind enough to prepare a special enlargement (Plate XXV.) for the present purpose, which brings out as many of the details of the original plate as can readily be shown in this rather unsatisfactory way. It may be said of all the plates that the beauty of the positives on glass from which they were made is for the most part lost. Contrasts that were before scarcely noticeable are now harsh and offensive, detail and definition is lost, and nothing is gained to offset these losses. In some cases the grain of the plate is especially conspicuous; this is particularly true of the great eruptive prominence from the Kenwood collection. To explain this it may be mentioned that our photographs were taken with a 50^{mm} focal image of the Sun, while the image photographed by Professor Schaeberle was 112^{mm} in diameter. In order to reproduce all the plates on the same scale, it was therefore necessary to enlarge the Kenwood negatives more than twice as much as Professor Schaeberle's. As the scale of the reproductions is about 16.2 inches to the solar diameter, an eightfold enlargement was required for our plates; this was sufficient to bring out the granulation together with the chance defects of the originals in a disagreeable manner. The sharpness of the photographs must be judged from the image of the prominence itself, and not from the outline of the metal disk which covers the Sun. The latter was necessarily out of focus, as it was considerably above the plane of the spectroheliograph slit, and separated from it by a plate of blue glass.

With these circumstances in mind the eclipse photograph by Professor Schaeberle, which may fairly be considered as one of the best of its kind, may be compared with the spectroheliograms. I think it will be seen that in sharpness of definition, and *apparently* in the rendering of faint details, the latter do not fall far behind. These are not shown as *average* results. They represent some of the best results obtained at the Kenwood Observatory. They serve, however, to give some idea of what can be photographed with apparatus which is open to very decided improvement. Were eclipse results obtained on the same dates available for comparison, such photographs would do much to assist in determining the exact nature of the apparent changes in prominence forms brought about by the reduction in brightness of the glare around the Sun.

I had intended to conclude this paper with some discussion of Professor Schaeberle's theory that prominences are made up of numberless interlacing streams of elliptical form, but the space which it has seemed necessary to give to the "white" prominences has already carried it beyond desirable limits, and further considerations must be deferred for the present.

GEORGE E. HALE.

KENWOOD OBSERVATORY,
April 11, 1896.

ON A NEW METHOD OF PREPARING PLATES SENSITIVE TO THE ULTRA-VIOLET RAYS.[1]

I.—PRELIMINARY PREPARATION OF THE PLATE FOR COATING WITH SILVER BROMIDE.

IF plates prepared as above are treated with hypo, the greater part of the developed picture flows away as soon as the remainder of the yellow ground of the plate forming the unexposed parts disappears. This defect may be prevented by:

(*a*) Preparing the silver bromide film very thin.

(*b*) Coating the glass plate with some binding material before depositing the silver bromide.

(*c*) Mixing the bromide itself with a binding material.

(a) With a thick film the developed picture rests upon a layer of unaltered silver bromide, and by the fixing this is replaced by an equally thick layer of fluid which causes the picture to be suspended close over the glass. If the tray is moved, the film forming the picture is broken up and floats off. With a thin coating the greater part of the image is reduced all through the film. The fixing solution then acts more on the sides of the reduced silver than underneath it, so that the undermined parts of the film remain fast to the glass along with the other parts and are prevented from being washed away. But the use of silver bromide without a binding material is not to be recommended. Even with a proper thickness of film, the plates require the greatest care after fixing.

In cases when the employment of a binding material is not permisible (as when it is desired to ascertain the behavior of the spectrum with pure silver haloid), it is better not to fix at all. In darkness the

[1] Continued from page 226.

plates can be preserved unchanged in color for a long time. If the plate must under any circumstances be fixed, then it is better to employ a gelatine bath first. This also gives the finished plate more resistance. The fixed image from a thin film of pure silver haloid on plain glass has no strength, and is very sensitive to mechanical pressure.

(b) If the glass plate to be sensitized is first coated with gelatine, then even a thick film of pure silver bromide holds so strongly that the fixing with hypo does it no injury.

For this substratum I use a warm 2 per cent. solution of gelatine which is liberally poured onto the carefully cleaned and warmed plate and allowed to flow over it and run off at one corner. The plate is then stood up to dry in a place free from dust on blotting paper, with the prepared side inwards, and coated soon afterwards with the silver bromide.

The coating of silver bromide is very sensitive to irregularities in the gelatine coating; particles of dust, burst air bubbles and inequalities in the coating spoil the deposition of the silver bromide and give rise to a number of defects in the plates, which in most cases do not appear till the development. The coating with gelatine must therefore be done with the greatest care. Above all, air bubbles must be avoided. Even the smallest bubbles burst, and where they are the surface of the glass is exposed, and this, in certain cases which will be referred to later, in consequence of the insensitiveness of the silver bromide deposited upon it, becomes uncovered on the developed plate all around them.

The gelatine coating should be as thin as possible. The thinner it is, so much the less will the almost unavoidable differences in its thickness affect the silver bromide film; the stronger the image sticks to the glass, the less stained the gelatine becomes in the developer. Another advantage to be noted, especially with very small plates, is that as the plates must be cut from the prepared side, the cutting can be done much more neatly and exactly through the film in proportion as the gelatine is thinner. (The plates cannot be cut from the back on account of the fragility of the bromide film.)

(c) If the bromide of silver is itself mixed with a binding material, then the substratum of gelatine is unnecessary. This can be done in a suitable way by precipitating the silver bromide from solutions containing gelatine. In this case the particles of bromide, as is well known, contain gelatine and, as I observed at the outset, hold very firmly when applied on glass and dried.

The proportion of gelatine in my silver bromide solution varied between 1:18,000 and 1:1550. Its influence on the sensitiveness of the plates will be considered later.

It should, however, be mentioned at once, that for reasons which will be explained hereafter, I now use the gelatine substratum for all plates, even when the silver bromide contains gelatine.

II. PREPARATION OF THE SILVER BROMIDE.

(*a*) *Without gelatine.*—To prepare silver bromide as a fine gradually deposited precipitate, requires very greatly diluted solutions and a large excess of potassium bromide. I dissolve 2.8 grams of potassium bromide in 4 liters of distilled water, and 2.0 grams of silver nitrate in 100^{cc} of distilled water, and in the light of the dark-room pour the silver solution in small quantities into the bromide solution, constantly stirring the while. The liquid so obtained is tolerably translucent and colored red by transmitted light, and after filtering is ready for the precipitation of the silver bromide. In this case I do not use the whole of the silver bromide, but content myself with what falls in one or two days. To wait till the fluid over the plate is quite clear would take weeks.

The liquid with the precipitate becomes visibly denser as soon as ammonia is added. The bromide also settles much quicker than before, and ten to twelve hours will be sufficient. For this purpose I add 30^{cc} of ammonia to the above solution.

(*b*) *With gelatine.*—To the solution of potassium bromide given above I add 0.2 gram of hard emulsion gelatine, dissolved by heat, and otherwise proceed as before. Ammonia also acts beneficially on the formation and settlement of the silver bromide precipitate.

All these methods yield a silver bromide which is only slightly sensitive even when prepared with warm solutions. Greater sensitiveness was obtained by prolonged heating of the suspended silver bromide. The greatly diluted solutions are not well adapted for this and better results can be obtained with an emulsion weak in gelatine. If this is dissolved in proper quantity in hot water, the silver bromide precipitates gradually. It also contains gelatine, but gives a more sensitive coating than bromide which is deposited from very dilute solutions.

The emulsion I use for this is composed as follows:

A		*B*	
Potassium bromide	12 grams.	Silver nitrate	15 grams
Emulsion gelatine	2 "	Distilled water	200^{cc}
Distilled water	200^{cc}		

A is dissolved with heat, and *B*, also warmed, is poured in very gradually in small quantities in the light of the dark-room. During the mixing *A* must be kept well stirred.

The unripened emulsion can be used at once for precipitating, but the plates are then scarcely more sensitive than in the former method. Greater sensitiveness must be obtained by warming or boiling the emulsion, adding ammonia or other means usually employed with sensitive gelatine emulsions as laid down in the text-books. The only precaution to be taken during the ripening is to keep the emulsion well shaken, as, owing to the small quantity of gelatine, a good deal of the bromide will settle to the bottom. 100^{cc} of this emulsion dissolved in 4 liters of water, shaken up and filtered several times, gives a good precipitating fluid. It is well to allow the solution to stand a few hours before use, in order to allow the heavier particles of dust and other impurities which may go through the filter to settle, so that at least the heaviest of them may be kept off the plate. By this precaution, the formation of a number of small defects on the plate, even if they may be almost microscopic, is avoided.

The silver bromide can also be obtained from ordinary gelatine dry plates, though the emulsions are of different degrees of richness in gelatine. The emulsion is dissolved in a suitable quantity of hot water, and the further procedure is as before. These plates also have great sensitiveness for the ultra-violet rays. My observations with them, however, have not extended beyond $\lambda 1700$. But I have no doubt that these plates would be useful beyond that point.

The employment of ordinary dry plates can only be considered when it is desired to prepare plates sensitive to the ultra-violet with the least expenditure of time, trouble and cost. When it is a matter of only a few experiments, or perhaps it is merely desired to ascertain the behavior of the new plates, it is better to take the silver bromide from the coating of commercial plates. For this purpose a plate of this kind is cut into slips 1^{cm} or 2^{cm} wide, which are placed in a flask full of hot water (0.5 to 0.6 liter for a plate $13^{cm} \times 18^{cm}$) and well shaken. As soon as the coating of emulsion has dissolved, the contents of the flask are filtered, allowed to stand quietly for about an hour, and then poured into the precipitating dish, in which a second dry plate has been laid with the coated side upwards.

III.—INCREASING THE SENSITIVENESS OF SILVER BROMIDE TO THE ULTRA-VIOLET RAYS.

The sensitiveness of silver bromide to the rays beyond λ 2200 may be increased by the addition of silver iodide. In the same way as gelatine emulsion plates with bromide of silver are improved by iodide, so may also be the plates sensitive to the ultra-violet. Plates have been tried containing 5, 10 and 20 per cent. of silver iodide, and better results have throughout been obtained than with pure silver bromide.

The iodide increases not only the sensitiveness but also the intensity and clearness. *This only obtains, however, when both the bromide and the iodide are precipitated together from the same solution.* A mixture of the two precipitated apart from one another gives plates of very ordinary sensitiveness. Pure silver bromo-iodide is consequently also very variably sensitive to the rays beyond λ 2200, according to the manner of its preparation, as bromo-iodide emulsions with gelatine are with respect to the rest of the spectrum.[1]

I give below the formula for preparing bromo-iodized plates sensitive to the ultra-violet, which have answered better than all others for my photographs of the shortest wave-lengths:

A		*B*	
Potassium bromide	6 grams	Silver nitrate	8.1 grams
" iodide	0.6 "	Distilled water	100cc
Emulsion gelatine	1 "		
Distilled water	100cc		

After melting the swollen gelatine, both solutions being heated to 50° or 60° C., *B* is poured in very small quantities into *A* in the dark room, being well and often stirred meanwhile, set in boiling water for half an hour and also well stirred, then allowed to cool 40° C., 4cc ammonia added and again well stirred up, allowed to cool further for half an hour or warmed in a water bath at not over 40° C. After that 64cc of the fluid is poured into 4 liters of warm water at not over 40° C., well stirred, filtered, and after standing for 1 to 2 hours, the silver bromo-iodide is left to settle as described before. After drying, the

[1] I have obtained better results with plates containing about 10 parts of silver iodide to 100 parts of silver bromide, than with any other plates. For photographing the most refrangible rays of the new spectral region I have used only bromo-iodide plates. It should, however, be mentioned that a year elapsed between the preparation and the exposure, during which time the specially high sensitiveness may have been acquired by an after ripening.

plates must be washed for a time in standing or quietly flowing water, which at first is frequently changed.

IV. THE SETTLING OF THE SILVER BROMIDE.

Glass developing trays with flat bottoms made of moulded glass are suitable for settling the silver bromide. The inside dimensions of the bottom should be at least five-eighths of an inch larger than the plate. After a good cleaning with sulphuric acid, the dish is filled to about three-fourths of its depth with the filtered bromide solution, and the plate, dusted on both sides with a soft brush, is laid down so that it is at least two-fifths of an inch from the farthest edge. The time required for settling varies according to the preparation of the silver bromide. As soon as the edges of the plate can be seen through the fluid it is time to empty the dish and dry the plate. The dish is inclined forward and the fluid runs off with a syphon reaching to the bottom of the dish in front of the plate. The remaining solution is soaked up carefully with blotting paper from one corner so as not to damage the surface of the plate. The plate can then be taken out of the dish. Care must be taken not to touch the film with the fingers. If the film contains gelatine, it will contract for some distance around the finger mark and probably damage the coating. The plates should be taken out of the dish by the edge and held by the lower side and be kept as nearly as possible horizontal. Then they are laid to dry in a place free from dust, but not in a drying box as for gelatine emulsion plates. A few hours are sufficient. The plates dry more quickly standing, only the film is easily split by so doing and shifts away in places; or the heavier particles may move downward and cause furrows which will develop as transparent lines with denser edges.

V.—THE DRY PLATES.

(*a*) *Before exposure.*—In drying, the sensitive coating of the plates will be distinctly more transparent for the visible light rays, especially if the silver bromide contains gelatine. I have had plates which while wet were only translucent, but after drying were completely transparent to my dark room light (stearine candle light filtered through three thicknesses of brown tissue paper).

After drying, silver bromide containing gelatine adheres very strongly to the plate; pure silver bromide on a gelatine coating is not so good, especially with a thick coating, and on a plain glass surface

makes such a loose deposit that its employment for photographic negatives is attended with great difficulties. However, when once they are dry these plates can be set up standing in water to remove the potash salts in the coating, which is as necessary in this as in the other preparations.

The coating is very sensitive to mechanical pressure. It will scarcely even bear dusting with a brush without injury. To direct pressure it is generally less sensitive. When cutting with a diamond, the rule may be laid direct on the sensitive side without fear of injury to the film. Under still stronger pressure many sensitive coatings change their properties. I came to this conclusion from the fact that plate numbers stamped on with a soft rubber stamp always develop intensely black, whereas the same method of marking in all other cases gives the numbers as clear as glass.

The color of the coating of the plates is, with silver bromide, white, with a trace of yellow; with a mixture of silver bromide 100 and silver iodide 5, somewhat yellower; with the bromide and iodide in the same proportions, precipitated together from the same solution, citron yellow, and with 10 parts of iodide, light orange yellow.

Pure silver haloid gives a dull coating; with gelatine it is more glossy. By the light of the dark room it generally appears faultless, except at the edges, which show uneven streaks. By daylight, however, it is different, and fogginess and unevenness of the deposit may often be noticed. On development, these appear as dense spots unless certain precautions are very carefully observed. Moreover, the film always contains some particles of dust, however carefully the plates may be prepared, and under the miscroscope these spoil the image and sometimes render it useless. Fortunately this only happens when the image of a line taken with a very fine and short slit opening falls upon impurities, and so becomes uncertain.

(*b*) *The photo-chemical coloring.*—My observations will here be confined to films containing gelatine, and even with these only to a few tried in direct sunlight. In presence of sunlight, the sensitive films are affected differently according to their composition.

Silver bromide is colored at first greenish blue, and becomes gray blue without gaining greater intensity. If only part of the plate is exposed, this appears surrounded by a greenish blue aureola, the result of total reflection, by which the rays are thrown off from the back of the plate. A mixture of iodide and bromide darkens much more

strongly than pure silver bromide. It becomes gray blue and shows only a trifling halo. The iodide and bromide precipitated together takes a still more intense gray blue color and shows almost no aureola.

(*c*) *The photographic coloring.*—The color acquired in development by plates sensitive to the ultra-violet is, as is universal in photography, quite different from the photo-chemical coloring. For development only pyro and soda are used. With normal exposure, the film of silver bromide is colored gray black, while that of the bromo-iodide is blackish brown. However, by suitable dilution of the developer both may be made darker and more intense. Of this more anon.

If a full exposure is given the image sometimes appears light brown and is bordered with dark brown. If the exposure is still further increased, solarization takes place. The exposed parts appear transparent, almost like clear glass, in the middle of an extensive halo; for this I burn 25^{cm} of magnesium ribbon, one to two centimeters in front of a plate, covered with a perforated screen. If the plate is prepared with silver iodide and bromide precipitated together, there is no solarization (I have used plates containing 5, 10 and 20 parts of AgI to 100 parts of AgBr). The exposed surface is then strongly blackened and stands out strongly from its wide transparent surroundings. This was also the case with prolonged exposures. All these experiments were made with plates containing gelatine. I have also tried silver bromide plates containing agar-agar, but found that they solarized even more readily than the gelatine plates. V. SCHUMANN.

Refraction in the Atmosphere of Jupiter.—M. Bélopolsky, in discussing the results of his spectrographic determination of the equatorial velocity of rotation of Jupiter (*A. N.* 3326), notes that the velocity determined in this way is less than that deduced from the observed rotation and micrometric measurements of the planet's diameter. Assuming a rotation period of $9^h\ 50^m$, different measures of the diameter give equatorial velocities varying from $12^{km}.1$ to $12^{km}.8$ per second, while the result of the spectrographic determination is $11^{km}.42$. M. Bélopolsky suggests that the measured diameter may be too great on account of refraction in the atmosphere of the planet, and points out that spectrographic determinations of the equatorial velocity of Saturn also give a result which is slightly too small.

At present the difference in question would seem to be too near the

probable error of measurement to warrant a definite conclusion as to its reality, but the point is worth remembering as a subject for investigation with improved instruments in the future.

A large Telescope for Potsdam.—We learn with pleasure that the Astrophysical Observatory at Potsdam is to have a large refracting telescope. With the 11-inch refractor hitherto used for the spectrographic researches of Professors Vogel and Scheiner, the motions in the line of sight of 51 stars were determined with great accuracy, but it was impossible to photograph stars appreciably fainter than the second magnitude with the large spectrograph. It is reported from Berlin that the aperture of the new telescope will be about thirty inches. The light-collecting power of such an instrument should be sufficient to bring stars of the third magnitude and some even fainter ones within reach of the large spectrograph, whose range will thus be trebled if not quadrupled.

Reviews.

RECENT SPECTROSCOPIC WORK OF EDER AND VALENTA.

Über drei verschiedene Spectren des Argons. Sitzber. d. K. Akad. d. W. Wien. CIV. Dec. 1895. *Über die Spectren von Kupfer, Silber und Gold. Denksch. d. K. Akad. d. W. Wien.* LXIII. 1896.

Two interesting papers by Eder and Valenta of Vienna have just appeared giving accounts of two series of researches. One is a preliminary contribution on "The Three Different Spectra of Argon," and the other is a memoir on the "Spectra of Copper, Silver and Gold." In all of their preceding work Eder and Valenta have used a prism spectroscope; but, having secured a Rowland concave grating of short focus, they are now applying it to various investigations. Their instrument is set up in the usual manner; the slit is fixed, and the moving arm carries the grating and camera box. Great precautions and skill seem to have been used in the adjustments of the apparatus; and so the results obtained command confidence. All the wave-lengths are reduced to Rowland's scale, the method being to use some comparison spectrum on the same plate. An alloy of zinc, cadmium, and lead was generally used for this purpose.

In the paper on the spectra of argon, the writers call attention to the previous work of Kayser and of Crookes, and to the well-known fact that argon gives two spectra, the "blue" and the "red," depending mainly upon the pressure of the gas and the nature of the discharge through it. The paper being a preliminary one, only a few wave-lengths are given, mainly in the extreme ultra-violet. But the main interest lies in certain observations, which were made for the first time. When the pressure is low (2 to 10^{mm}) in the tube containing argon, the red spectrum is absent almost entirely; and the blue spectrum is prominent. But as the pressure is increased to 20^{mm}, the character of the spectrum is changed; and, if a very large induction coil with large condensers is used, a new spectrum is observed, which Eder and Valenta call the "white" spectrum. Some of the lines in the blue spectrum remain entirely unchanged; but others shift their positions by as much as $\frac{1}{2}$ to 1 Ångström unit. This is claimed to be a genuine shift, not an apparent one owing to unsymmetrical shading. This is certainly a

remarkable observation. If the pressure in the tube is extremely low ($\frac{1}{10}$ to 2^{mm}) the red spectrum may be made to entirely disappear by simply continuing the discharge through it for a long enough time. The writers also examined the glow at the positive and negative poles, and found the two spectra identical. Crookes, on the other hand, says that he has observed the red spectrum at the positive pole, and the blue at the negative.

In examining the spectra of copper, silver and gold, special precautions were taken to secure pure metals; and sparks were passed between these pure electrodes in an atmosphere of hydrogen. In each case there is a full account given of the work done by previous observers, and a comparison of results. The authors, though, have overlooked the paper by Crew and Tatnall in *Astronomy and Astrophysics*, November 1894, "On a New Method of Mapping the Spectra of Metals," which contains a list of wave-lengths of copper lines. The only previous investigations that are comparable at all with that of Eder and Valenta are Kayser and Runge's on the arc-spectra of these elements, Crew and Tatnall's on the arc-spectrum of copper, and Trowbridge and Sabine's on the spark-spectrum of copper. There is excellent agreement between the results of the two researches on the spark-spectrum, and also between those of the two on the arc-spectrum. But between the spark and the arc-spectra there are many differences. As Eder and Valenta pointed out in their work on the spark-and arc-spectra of zinc and cadmium, the character of the spectrum changes greatly when the discharge is changed from an arc to a spark; some lines disappear, many new ones appear, and the difference in wave-length between a spark-line and an arc-line may be very slight. So also in this work on copper, silver and gold. There are many discrepancies between the wave-lengths and intensities of lines observed by Eder and Valenta in the spark-spectrum, and those observed by Kayser and Runge in the arc-spectrum; but it seems extremely probable that these differences are genuine ones, not accidental. This might almost be expected. For in the arc the vapor is at a fairly constant temperature and pressure; whereas in the spark discharge temperature and pressure have no meaning. Each time a spark passes, portions of matter have their velocity tremendously increased; but the process is both sudden and irregular, so that it is doubtful if there is even an average condition of pressure or temperature which is constant. Consequently spark-spectra are necessarily more complicated and irregular in every way than arc-spectra.

This memoir on the spectra of copper, silver and gold is especially interesting and important because in the introduction to it Eder and Valenta give a detailed account of their methods of adjustment of the apparatus, and also a most satisfactory description of the different solutions and stains (or "light filters" as they call them), which they use to cut out overlapping spectra.

J. S. A.

Report of the Smithsonian Astrophysical Observatory for the year 1895. S. P. LANGLEY. Smithsonian Report for 1895. Pp. 74–80.

It was in 1891, or about five years ago, that the important work on the bolometric investigation of the infra-red solar spectrum, which was begun by Professor Langley at Allegheny nearly twenty years ago, was recommenced at the Smithsonian Astrophysical Observatory by a new method and with greatly improved apparatus. It is, therefore, somewhat surprising to find the present report, which is the fourth annual report issued from the Observatory, devoted almost entirely to a discussion of the instrumental conditions of working and of those elementary sources of error which are generally considered before such an important investigation is undertaken, or at least, before any of its results are published. The logic and practical advantages of this order of procedure are indisputable and are recognized by every scientific man. It is, therefore, only fair to Professor Hallock and to myself to point out that all of the sources of error which the report deals with, as well as others of almost equal importance which are not there considered, were not only fully recognized, but carefully investigated three years ago, while we were (successively) the senior assistants in the Observatory. The present report contains nothing upon this point that could not have been stated, and in fact was stated in substance in the reports for 1892 and 1893. In this connection it will be well to indicate a misstatement in regard to one of the important sources of error, *i. e.*, that which is spoken of as due to a change in *potential* of the batteries. The true source of difficulty is not the change of potential in itself, but the *resulting change* in the strength of current in the bridge circuit as a whole. A change of potential of the batteries is of course only *one* of the causes which may produce this latter effect. To avoid it, it is necessary to keep the current constant to within about one-millionth of an ampere, and this the writer was accustomed to do by the use of a delicate Thomson galvanometer connected in shunt to the bridge cir-

cuit. Another of the errors spoken of, viz., that due to a change of temperature of one of the bridge coils, is of such a fundamental character and so generally recognized in accurate resistance measurements, as to hardly have needed mention. In regard to the errors arising from magnetic and seismic disturbances, it would seem that their importance had been somewhat exaggerated. We can never get rid of all disturbances of this nature, no matter where we may locate our laboratories, and it would seem better to overcome the difficulties due to them by means which are now well known and are comparatively simple of application, than to go to the expense and inconvenience of relocating an already fairly well established observatory. Vibration may practically be completely absorbed by mounting the instruments on a series of heavy slabs of stone separated from each other by blocks of soft rubber (as described in my article on the Galvanometer in the *Phil. Mag.* for Dec., 1894), or by floating them in mercury (Michelson's method), and magnetic disturbances guarded against by a soft iron enclosing case. The work of Professor Rowland and his associates and students at Johns Hopkins in the measurement of wave-lengths, both in the visible and the infra-red spectrum, and the work of Professor Boys at Oxford in the determination of the Newtonian Constant (reviewed in the last number of this JOURNAL), show what may be accomplished in the way of exact measurement under natural conditions (of vibration, etc.) far more unfavorable than those which exist (or did exist in 1892–3) at the Smithsonian Observatory. We do not wish to be understood as in any way depreciating the great advantages which result from the most favorable location of our laboratories and observatories: we only wish to question whether undue emphasis is not perhaps laid on this condition, especially in the statement made at the close of the report that, "It should finally be repeated as the most important conclusion of the year, that the final degree of precision attainable can never be reached in the present site."

One thing which deserves commendation in this report, is the acknowledgment of the fact that the so-called "linear translation" or "cylindric" of the region between wave-lengths 14000 and 22000, which was shown at the British Association meeting for 1894, and reproduced and commented upon at some length in the Observatory report for the same year, cannot be regarded as a trustworthy representation of the region in question. It is unfortunate that this representation was ever presented at all; still more unfortunate that such prominence should have been given to it as it received. In the paper

read before the British Association, at which time the representation in question was first shown, Mr. Langley says, "Now considering that the part of the infra-red solar spectrum under review, extends through nearly two degrees. . . . . we may see for ourselves that at any rate over 2000 lines if they exist can be mapped. But these lines do exist, the whole of this new region being apparently as intimately filled with them as the visible spectrum by the Fraunhofer lines. In further evidence of this I now show a portion of the lower spectrum in the comparatively unknown part extending from $\lambda = 1^{\mu}.4$ to $\lambda = 2^{\mu}.2$, including the great band Ω shown as a single inflection in my first communication to this Association, but here resolved into thirty or more subordinate lines . . . . in the small portion here exhibited it may be seen that about 200 lines are discriminated." Again in the Observatory report for 1894 he further adds, "The result of the work has been extremely satisfactory so far as regards the number and importance of the lines found. The accompanying illustration showing a portion of the infra-red spectrum from the region $1^{\mu}.4$ to $2^{\mu}.2$, beyond what a few years ago was considered the limit of the infra-red spectrum, will show the detail and clearness with which the present apparatus is capable of rendering what can, only in the absence of a better word, be called the 'appearance' of this region. . . . The portion of the infra-red spectrum shown, which is that at present furthest advanced, has been gone over several times, and each of the more than 200 lines which occupy this plate has been verified by many observations. The plate shows but a small part of the region which is now being mapped, in all of which it is believed the results will be equally encouraging." [1]

This plate was also reproduced in the second number of this JOURNAL in illustration of a review of the work by Professor Hale and has been frequently copied in other journals. But as far as I have been able to find, Professor Hale is the only one who has questioned the truth or accuracy of the representation, and his criticisms were directed only against the method of translation or reproduction from the original energy curve. Now whatever may be the degree of confidence placed in the original energy curves and in the method of obtaining these "cylindrics" from them, there is a very simple criterion

[1] I have not been able to find either in the British Association paper or in the Observatory reports, the statement which Professor Langley quotes that this plate of the spectrum "was presented only in illustration" and was "not to be treated as a criterion of the final results." Without this the statements quoted above would certainly leave the impression that the results spoken of were regarded as trustworthy.

which has been entirely overlooked and which declares at once absolutely against the truth of the final result. *Many of the lines shown are closer together than the spectroscope used* (a single rock-salt prism of about 9^{cm} aperture) *could theoretically resolve.* Since the width of the slit with which the energy curves were taken, was never less than $0^{mm}.3$, the *purity* of the spectrum in this region ($\lambda = 20000$) was only about one-half the theoretical resolving power, and the absolute impossibility of recording all of the lines shown even under *perfect* conditions of observation is at once evident. This shows again how important it is, especially in spectroscopic work, to understand clearly the optical capabilities and limitations of our instruments before drawing conclusions from either visual, photographic or bolometric observations. As Professor Keeler has very aptly said in a recent review, "Expressions of individual opinion have no weight in matters which are governed by purely physical laws." But there is also another special lesson to be drawn from this case, and that is the superiority of the energy curve itself to any "linear translation" or "cylindric" as a representation of bolometric results. No such erroneous conclusions could have been drawn from the energy curves of this region had they been presented in the same way that those showing the whole of the infra-red region were presented, for it would have been evident at once that the minute deflections which were translated into lines in the cylindric were accidental and not real. No question can be raised as to the accuracy and truthfulness of the main features of the three superposed curves which were shown in the report for 1894, and in this JOURNAL in the article already referred to. The results expressed by these curves were certainly sufficiently important and represented sufficient advance in themselves to have made it unnecessary to accompany them with maps in regard to the truth of which there could have been any question.

It is a satisfaction to note that in spite of the recent retrenchment of national expenses and the consequent reduction in the appropriations for nearly all of the governmental departments, there has been no reduction in that for the prosecution of this work for the present year. The government appropriations for this work alone have already amounted to nearly $50,000: as large as if not a larger sum than has ever before been available for any one scientific investigation, but no larger perhaps than is commensurate with its interest and importance. It is to be hoped that this generous support will be continued in the future as it has been in the past.

F. L. O. WADSWORTH.

Recent Publications.

A LIST of the titles of recent publications on astrophysical and allied subjects will be printed in each number of THE ASTROPHYSICAL JOURNAL. In order that these bibliographies may be as complete as possible, authors are requested to send copies of their papers to both Editors.

For convenience of reference, the titles are classified in thirteen sections.

1. THE SUN.

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2. THE SOLAR SPECTRUM, INFRA-RED, VISIBLE, AND ULTRA-VIOLET.

BÉLOPOLSKY, A. Observations des raies renversées dans le spectre des protubérances faites à Poulkovo. Mem. Spettr. Ital. **25**, 23–26, 1896.

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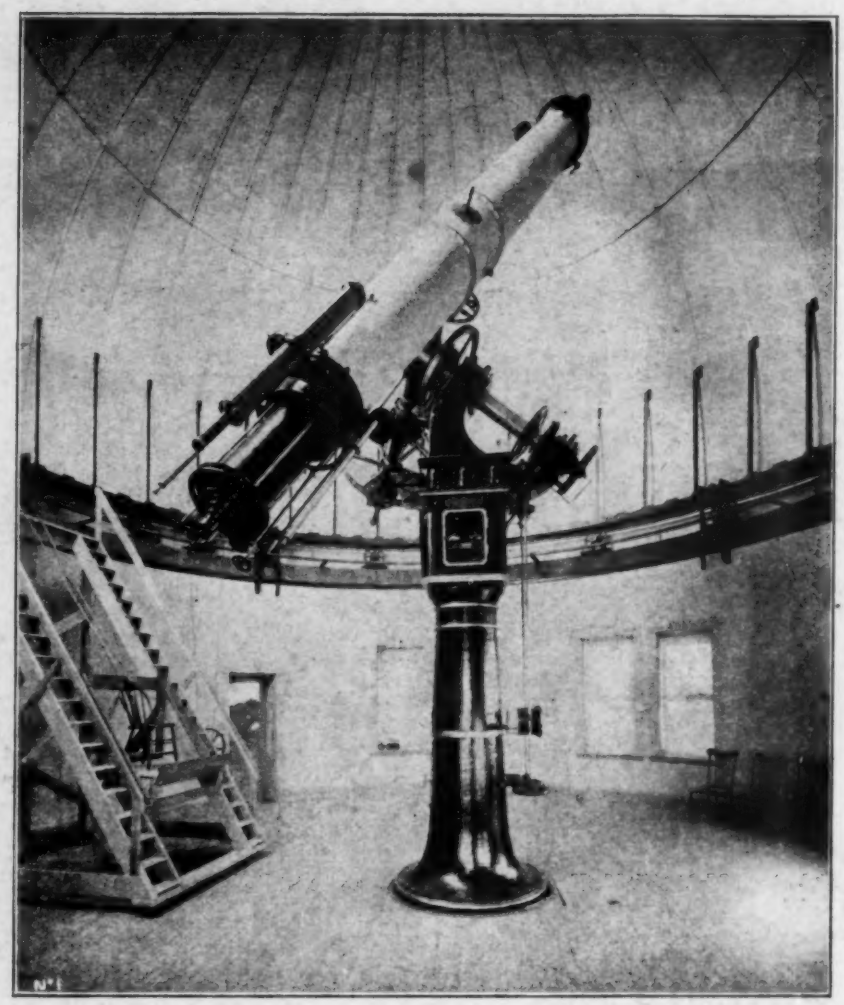

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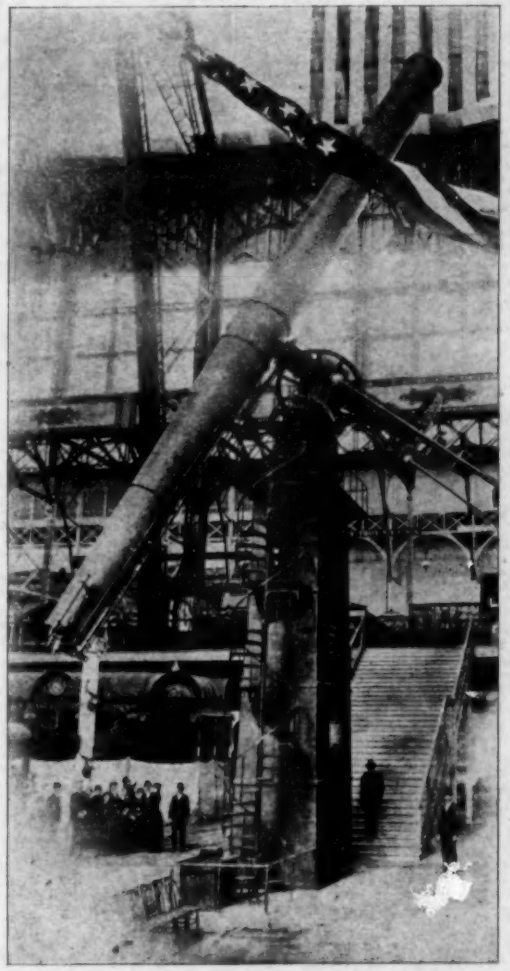

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